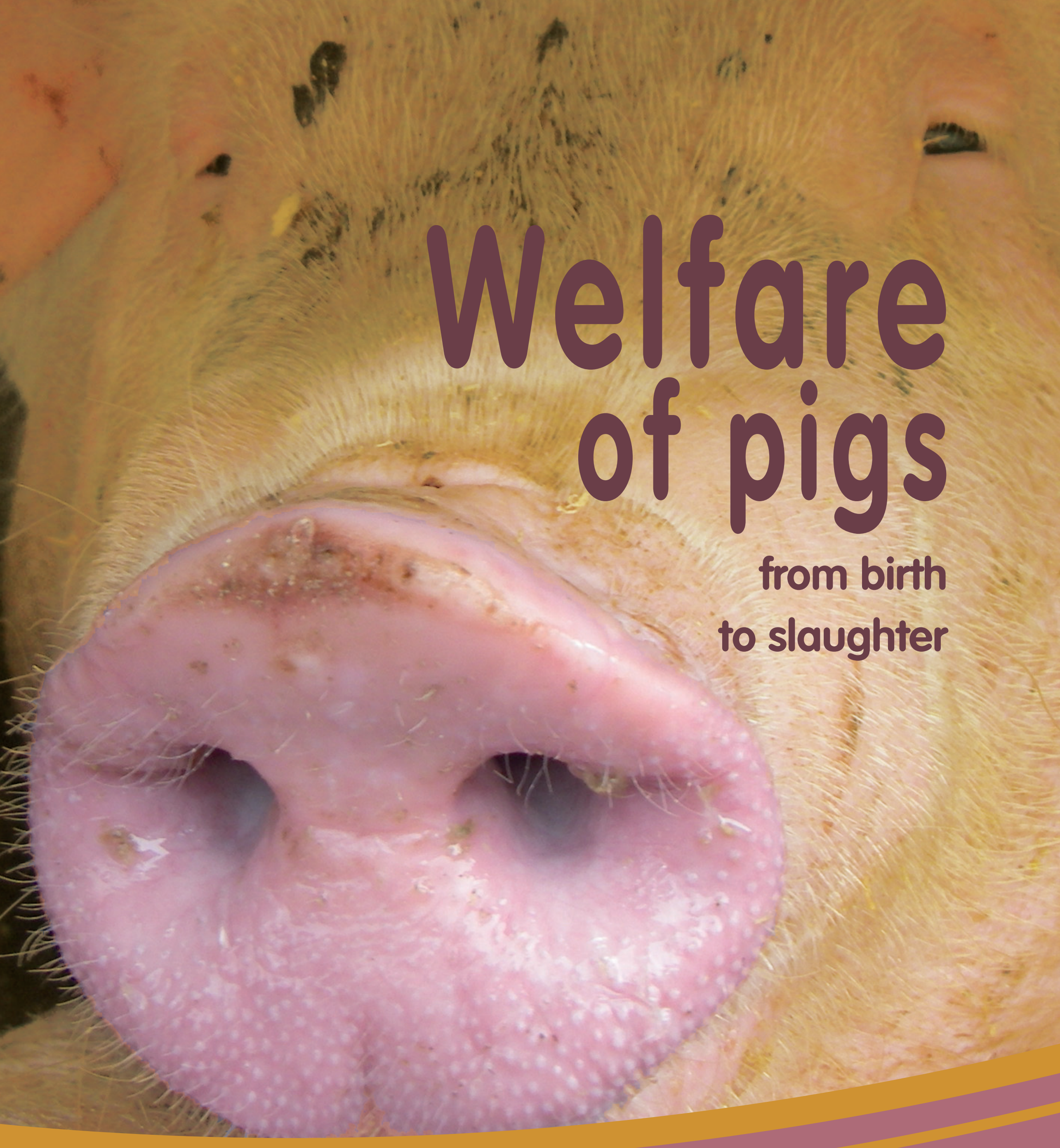

Welfare of pigs

from birth to slaughter

edited by:
Luigi Faucitano
Allan L. Schaefer

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Wageningen Academic Publishers

éditions Quæ

ISBN: 978-90-8686-066-1
e-ISBN: 978-90-8686-637-3
DOI: 10.3920/978-90-8686-637-3

ISBN 978-2-7592-0086-3

First published, 2008

Wageningen Academic Publishers
The Netherlands
&
Éditions Quæ, Versailles
France

2008

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Preface

The procurement and use of food of animal origin has been a defining characteristic of our omnivorous species throughout our existence. Humans have also been very creative in finding a multitude of animal sources of food varying from bison and bees to swine and sardines. Long before biochemistry and nutrition research disciplines were even thought of it was nonetheless well understood by those families, those tribes and those societies who availed themselves of food of animal origin that a survival and health advantage was realised by including food of animal origin in their diet. As a result, whether in a hunter-gathering society or agrarian society, considerable cooperative effort has been expended in obtaining food from animals. Simultaneously, for most societies, the realisation of the importance of animals in the human diet has been matched by the reverence for the animals themselves. With the arguable exception of unsustainable gladiatorial events, true practitioners of animal husbandry, the farmers, have retained a respect and care for the animals they raise.

However, as our societies have become more technological and urban this direct connection and reverence for food animals has become less apparent. In some ways, we are rediscovering, through the animal welfare movement, what our ancestors have always known. Animals are important to us and as sentient beings they deserve consideration and respect.

Animal welfare is a complex topic and as discussed in the concluding chapter, includes many pragmatic as well as many philosophical issues. Management decisions regarding the care and maintenance of domestic animals can at times seem to be conflicted. With pigs for example, the improved care and survivability of new born piglets is assumed to be facilitated by a farrowing crate. However, that same crate restricts the free movement and outright welfare of the sow. Similarly, loose sow housing systems are often viewed as improvements with respect to sow movement and freedom yet at the same time can cause increased levels of aggression and degraded welfare for a subordinate sow. Understanding how management decisions impact on animals and how a balance might be struck within such environments is what the chapter authors in this book have strived to provide. Consideration of the welfare requirements of animals in agricultural production systems is no longer simply an interesting topic of academic debate. Maintaining high animal welfare standards is an obligatory requirement and responsibility in any modern and progressive animal production system today. There are several excellent reviews and texts relating to specific aspects of swine production and selective swine welfare topics. However, the objective of the present book is to provide a science-based reference text which covers all aspects of swine production. This current book covers swine welfare topics within the total production paradigm from breeding and farrowing to finishing, transport and slaughter and is a unique and complete reference text regarding an important agricultural species in this regard. This unique and comprehensive work is written by renowned experts and accomplished scientists in the field who are themselves engaged in active research labs and who have demonstrated their devotion to animal care and welfare. The authors, from several continents where intensive swine production is practiced, offer a global perspective of swine welfare. The book provides an in-depth scientific review and empirical assessment of the concepts, knowledge and technology practiced in the swine industry today. The book is written within the context of what welfare objectively is and how welfare is objectively measured. This work will be of interest and relevance to academics, students, animal welfare and industry associations and all those involved in and who care about the humane production and rearing of swine.

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Chapter 1. Welfare concepts

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Abstract

The concepts of welfare, need, stress, health, pain, emotion and feeling are defined and the relationships amongst these are discussed. Welfare is a broad term, of which health and feelings are important parts. There has been rapid development in recent years in the scientific assessment of animal welfare. This information has been used in formulating laws about how animals should be housed, managed and treated. Where welfare is poor, the best overall assessment of welfare is a function of the severity of effect on the individual and the duration of that effect. Efforts should be made to evaluate how good welfare is as well as the extent of any poor welfare.

Keywords: stress, welfare, feelings, health, pain

1. Welfare definition

The welfare of animals is regarded as particularly important by many people and is a key factor when determining whether or not a system or procedure involving animals is sustainable (Broom, 2001a). However, the term welfare requires strict definition if it is to be used effectively and consistently. A clearly defined concept of welfare is needed for use in precise scientific measurements, in legal documents and in public statements or discussion. If animal welfare is to be compared in different situations or evaluated in a specific situation, it must be assessed in an objective way. The assessment of welfare should be quite separate from any ethical judgment but, once an assessment is completed, it should provide information which can be used to take decisions about the ethics of a situation.

A useful definition of animal welfare must refer to a characteristic of the individual animal rather than something given to the animal by man. The welfare of an individual may well improve as a result of something given to it, but the thing given is not itself welfare. The loose use of welfare with reference to payments to poor people is irrelevant to the scientific or legal meaning. However, it is accurate to refer to changes in the welfare of an initially hungry person who uses a payment to obtain food and then eats the food. We can use the word welfare in relation to a person, as above, or an animal which is wild or is captive on a farm, in a zoo, in a laboratory, or in a human home. Effects on welfare which can be described include those of disease, injury, starvation, beneficial stimulation, social interactions, housing conditions, deliberate or accidental ill treatment, human handling, transport, laboratory procedures, various mutilations, veterinary treatment or genetic change by conventional breeding or genetic engineering.

We have to define welfare in such a way that it can be readily related to other concepts such as: needs, freedoms, happiness, coping, control, predictability, feelings, suffering, pain, anxiety, fear, boredom, stress and health. Animals vary in the extent to which they are aware of themselves (DeGrazia, 1996) and of their interactions with their environment, including their ability to experience pleasurable states such as happiness and aversive states such as pain, fear and grief (Panksepp, 1998). This capacity may be referred to as their degree of sentience. *A sentient being is one that has some ability: to evaluate the actions of others in relation to itself and third parties, to remember some of its own actions and their consequences, to assess risk, to have some feelings and to have some degree of awareness* (Broom, 2006b). *Awareness is defined here as a state in which complex brain analysis is used to process sensory stimuli or constructs based on memory* (Broom, 1998).

If, at some particular time, an individual has no problems to deal with, that individual is likely to be in a good state, where that state includes physical condition, physiological functioning, good feelings, brain state and behaviour. Another individual may face problems in life which are such that it is unable to cope with them. *Coping implies having control of mental and bodily stability* and prolonged failure to cope results in failure to grow, failure to reproduce, or death (Broom, 2001c). A third individual might face problems but, using its array of coping mechanisms, be able to cope with difficulty. The second and third individuals are likely to show some direct signs of their potential failure to cope or difficulty in coping and they are also likely to have had bad feelings associated with their situations. *The welfare of an individual is its state as regards its attempts to cope with its environment* (Broom, 1986). This definition refers to a characteristic of the individual at the time. The origin of the concept is how well the individual is faring or travelling through life and the definition refers to state at a particular time (for further discussion, see Broom, 1991a,b, 1993, 1996; Broom and Johnson, 2000). The concept refers to the state of the individual on a scale from very good to very poor. This is a measurable state and any measurement should be independent of ethical considerations. When considering how to assess the welfare of an individual, it is necessary to start with knowledge of the biology of the animal. The state may be good or poor, however, in either case, in addition to direct measures of the state, attempts should be made to measure those feelings which are a part of the state of the individual. *A feeling is a brain construct involving at least perceptual awareness which is associated with a life regulating system, is recognisable* *by the individual when it recurs and may change behaviour or act as a reinforcer in learning* (Broom, 1998). As explained later (Section 3) feelings are generally adaptive and are aspects of coping systems. The affective state of the individual (Panksepp, 1998) with its balance of positive and negative feelings, is a key point of the welfare of an individual. *Suffering occurs when one or more negative, unpleasant feelings continue for more than a few seconds.*

This definition of welfare has several implications (Broom and Johnson, 2000), some of which are discussed in more detail later:

1. Welfare is a characteristic of an animal, not something given to it. In recent colloquial American usage, welfare can refer to a service or other resource given to an individual, but that is entirely different from this scientific usage. Human action may improve animal welfare, but an action or resource provided should not be referred to as welfare.
2. If welfare were viewed as an absolute state that either existed or did not exist then the concept of welfare would be of little use when discussing the effects on individuals of various conditions in life or of potentially harmful or beneficial procedures. It is essential that the concept be defined in such a way that welfare is amenable to measurement. Once the possibility of measurement is accepted, welfare has to vary over a range. If there is a scale of welfare and the welfare of an individual might improve on this scale, it must also be possible for it to go down the scale. There are many scientists assessing the welfare of animals who accept that welfare can get better or can get poorer (Curtis, 1986; Duncan, 1987). It is therefore illogical to try to use welfare as an absolute state or to limit the term to the good end of the scale. Welfare can be poor as well as good.
   Good welfare with associated pleasure or happiness is an essential part of the welfare concept but the view of welfare as referring only to something good or 'conducive to a good or preferable life' (Tannenbaum, 1991) is not tenable if the concept is to be practically and scientifically useful. Fraser (1993), referring to well-being as the state of the animal, advocates assessing it in terms of level of biological functioning such as injury or malnutrition, extent of suffering and amount of positive experience. He uses 'well-being' to refer to scales of how good the animal's condition is.
3. Welfare can be measured in a scientific way that is independent of moral considerations. Welfare measurements should be based on a knowledge of the biology of the species and, in particular, on what is known of the methods used by animals to try to cope with difficulties and of signs that coping attempts are failing. The measurement and its interpretation should be objective. Once the welfare has been described, moral decisions can be taken.
4. An animal's welfare is poor when it is having difficulty in coping or is failing to cope. Failure to cope implies fitness reduction and hence stress (See Section 4

below). However, there are many circumstances in which welfare is poor without there being any effect on biological fitness. This occurs if, for example, animals are in pain, they feel fear, or they have difficulty controlling their interactions with their environment because of (a) frustration, (b) absence of some important stimulus, (c) insufficient stimulation, (d) overstimulation or (e) too much unpredictability (Wiepkema, 1985).

If two situations are compared, and individuals in one situation are in slight pain but those in the other situation are in severe pain, then welfare is poorer in the second situation even if the pain or its cause does not result in any long-term consequences, such as a reduction in fitness. Pain, or other effects listed above, may not affect growth, reproduction, pathology or life expectancy, but it does mean poor welfare.

5. Fraser (1993), like Broom (1986) and Broom and Johnson (2000), draws a conceptual parallel with the term 'health' which is encompassed within the term welfare. Like welfare, health can refer to a range of states and can be qualified as either 'good' or 'poor' (see section 5 below).
6. Animals may use a variety of methods when trying to cope, and there are various consequences of failure to cope. Any one of a variety of measurements can therefore indicate that welfare is poor, and the fact that a measure, such as growth, is normal does not mean that welfare is good.
7. Pain and suffering are important aspects of poor welfare (see section 6 below). Even though some pain and suffering may be tolerated in order that some important objective to be attained, both of these involve increased difficulty in coping with the environment and hence poorer welfare.
8. Welfare is affected by what freedoms are given to individuals and by the needs of individuals, but it is not necessary to refer to these concepts when specifying welfare.

The term 'well-being' is often used interchangeably with 'welfare', but well-being is often used in a looser, less precise way. Welfare is the word used in English versions of modern European legislation. Some other languages have only one word that can be used to translate either welfare or well-being. The words which are equivalent to welfare in other languages, and which are used in identical legislation, have various origins: for example Wohlergehen, Wohlbefinden and Tiergerechtheit in German, welzijn in Dutch, bien-être in French, bem estar in Portuguese, bienestar in Spanish, velfaerd in Danish and dobrostan in Polish. Welzijn, bien-être, bem estar and bienestar are very similar to well-being in origin but are used by scientists and legislators in much the same way as English speakers use welfare. Dobrostan is close in use to welfare as defined in this paper Wohlergehen and velfaerd have a wider meaning but velfaerd is used specifically in legislation.

2. Welfare and needs

Most scientists involved in welfare research would agree with Appleby (1997) that a range of components of that environment, each of which is to some extent variable, should be considered when attempting to determine what is an appropriate environment for an animal. The environment is appropriate if it allows the animal to satisfy its needs. Animals have a range of functional systems controlling body temperature, nutritional state, social interactions, etc. (Broom, 1981). Together, these functional systems allow the individual to control its interactions with its environment and hence to keep each aspect of its state within a tolerable range. The allocation of time and resources to different physiological or behavioural activities, either within a functional system or between systems, is controlled by motivational mechanisms. When an animal is actually or potentially homeostatically maladjusted, or when it must carry out an action because of some environmental situation, we say that it has a need. *A need can be defined as a requirement, which is part of the basic biology of an animal, to obtain a particular resource or respond to a particular environmental or bodily stimulus* (Broom, 2001a). As pointed out by Broom (1997), these include needs for particular resources and needs to carry out actions whose function is to obtain an objective (Toates and Jensen 1991, Broom 1996). Needs can be identified by studies of motivation and by assessing the welfare of individuals whose needs are not satisfied (Hughes and Duncan, 1988a,b; Dawkins, 1990; Broom and Johnson, 2000).

Control systems have evolved in animals in such a way that the means of obtaining a particular objective have become important to the individual animal. Some needs are for particular resources, such as water or heat, the animal may also need to perform a certain behaviour. It may be seriously affected in an adverse way if unable to carry out the activity, even in the presence of the ultimate objective of the activity. For example, rats and ostriches will work, in the sense of carrying out actions which result in food presentation, even in the presence of food. In the same way, pigs need to root in soil or some similar substratum (Hutson, 1989), hens need to dust-bathe (Vestergaard, 1980) and both of these species need to build a nest before giving birth or laying eggs (Brantas, 1980; Arey, 1992). In all of these different examples, the need itself is not physiological or behavioural but is in the brain so is not physiological or ethological. It is the fulfillment of needs which requires physiological change or certain behaviour to be shown, and this has led to the use of 'biological needs' or just 'needs' in later Recommendations of the Council of Europe. Examples from the preamble of the Recommendations for pigs are 'environment and management have to fulfil the animal's biological needs rather than trying to adapt the animals to the environment by procedures such as mutilations' and there should be research 'to ensure that the needs of the pigs are met and hence their welfare, including their health, is good'.

Needs vary in urgency and the consequences if they are not satisfied range from those which are life-threatening to those which are relatively harmless in the short-term (Broom and Johnson, 2000). This range of meaning of need can be expressed in German by two words *Bedarf* and *Bedurfniss*. A *Bedarf* is a need which must be satisfied if life is to continue whereas a *Bedurfniss* is a need which the individual wishes to be satisfied. Since we know that strong preferences by an individual for or against a resource or activity usually relate to something important for the biological success of that individual, a *Bedurfniss* has to be considered very carefully in relation to welfare.

The term welfare is used in the European Convention for the Protection of Animals Kept for Farming Purposes (1976), for example Article 2 refers to 'principles of animal welfare laid down in Articles 3 to 7' and Article 7 refers to what is 'necessary to safeguard the welfare of the animals'. The Directives and Regulations of the European Union which relate to the protection of animals, also refer to welfare, health, suffering and needs. For example, in Directive 91/630/EEC laying down minimum standards for the protection of pigs: it is stated that research must 'take into account the welfare of sows in varying degrees of confinement' (Article 6). However, despite the regular use of scientific reports on animal welfare matters, the phraseology of legislation often fails to use terms like welfare and needs in an up-to-date precise way.

In all of this terminology it is important that a distinction should be made between what humans do and the effects on animals. Animal protection is a human activity and we have obligations towards animals which we use. Humans can be cruel or humane or kind towards animals. Regulation EEC 3254/91 concerning the ban on leghold traps refers to 'developing humane trapping methods' (Article 3.2), implying, as most scientists do, that for a trap to be humane, the welfare of the trapped animal must be good to a certain high degree. Legislation on slaughter and transport also uses these terms.

Some needs are associated with feelings and these feelings are likely to change when the need is satisfied (Broom, 1999). When there are no needs which have to be satisfied immediately and the animal's welfare is good, the animal is likely to experience positive feelings. Likewise, when there are unsatisfied needs and welfare is poor, there will often be bad feelings. Feelings will usually result in changed preferences; hence preferences can give some useful information about needs. The strength of preference is best assessed using the consumer surplus index (Kirkden *et al.*, 2003). Other information about needs is obtained by observing the abnormalities of behaviour and physiology which result when needs are not satisfied.

3. Welfare and feelings

The feelings of an animal are an extremely important part of its welfare (Broom, 1991b, 2003). However, whilst we have many measures that give us some information about injury, disease and both behavioural and physiological attempts to cope with the individual's environment, fewer studies tell us about the feelings of the animal. Information can be obtained about feelings using preference studies and other information giving indirect information about feelings can be obtained from studies of physiological and behavioural responses of animals.

As discussed above, feelings are aspects of an individual's biology which must have evolved to help in survival (Broom, 1998), just as aspects of anatomy, physiology and behaviour have evolved. They are used in order to maximise its fitness, often by helping it to cope with its environment. It is also possible, as with any other aspect of the biology of an individual, that some feelings do not confer any advantage on the animal but are epiphenomena of neural activity (Broom and Johnson, 2000). The coping systems used by animals operate on different time scales. Some must operate during a few seconds in order to be effectual, others take hours or months. Optimal decision-making depends not only on an evaluation of energetic costs and benefits but on the urgency of action, in other words the costs associated with injury, death or failure to find a mate (Broom, 1981). In the fastest acting urgent coping responses, such as avoidance of predator attack or risk of immediate injury, fear plays an important role in the immediate response and both fear and pain may facilitate future learning of such situations are encountered again. In longer time-scale coping procedures, where various risks to the fitness of the individual are involved, feelings rather than just cognitive processes are amongst the causal factors affecting what decisions are taken. In attempts to deal with very long-term problems which may harm the individual, aspects of suffering contribute significantly to how the individual tries to cope. In the organisation of behaviour so as to achieve important objectives, pleasurable feelings and the expectation that these will occur have a substantial influence. For example, the taste of a preferred food may lead to pleasure and this may increase the likelihood that a particular route is taken to allow a visit to the source of that food. The general hypothesis advanced is that whenever a situation exists where decisions are taken which have a big effect on the survival or potential reproductive output of the individual, it is likely that feelings will be involved. This argument applies to all animals with complex nervous systems, such as vertebrates and cephalopods, and not just to humans. Feelings are not just a minor influence on coping systems, they are a very important part of them.

In circumstances where individuals are starting to lose control and fail to cope, there may be unpleasant feelings. These feelings might have a role in damage limitation that is functional. However they might also occur when the individual is not coping at all and the feelings have no survival function then. Extreme suffering or despair are probably not adaptive feelings but an observer of the same species might benefit and a scientist might use indications of such feelings, such as certain postures and absence of responses to stimuli that would normally elicit a response, to deduce that the animal is not coping.

If the definition of welfare were limited to the feelings of the individual as has been proposed by Duncan and Petherick (1991), it would not be possible to refer to the welfare of a person or an individual of another species which had no feelings because it was asleep, or anaesthetised, or drugged, or suffering from a disease which affects awareness. A further problem, if only feelings were considered, is that a great deal of evidence about welfare like the presence of neuromas, extreme physiological responses or various abnormalities of behaviour, immunosuppression, disease, inability to grow and reproduce, or reduced life expectancy would not be taken as evidence of poor welfare unless bad feelings could be demonstrated to be associated with them. Evidence about feelings must be considered for it is important in welfare assessment but to neglect so many other measures is illogical and harmful to the assessment of welfare, and hence to attempts to improve welfare.

In some areas of animal welfare research it is difficult to identify the subjective experiences of an animal experimentally. For example it would be difficult to assess the effects of different stunning procedures using preference tests. Disease effects are also difficult to assess using preference tests. There are also problems in interpreting strong preferences for harmful foods or drugs. However, research on the best housing conditions and handling procedures for animals can benefit greatly from studies of preferences which give information about the subjective experiences of animals. Both preference studies and direct monitoring of welfare have an important role in animal welfare research. Welfare assessment should involve a combination of studies and of other factors providing information about coping.

4. Welfare and stress

The word stress should be used for that part of poor welfare which involves failure to cope. If the control systems regulating body state and responding to dangers are not able to prevent displacement of state outside the tolerable range, a situation of different biological importance is reached. The use of the term stress should be restricted to the common public use of the word to refer to a deleterious effect on an individual (Broom and Johnson, 2000). However, the usage of the term stress to refer to an environmental change which affects an organism, a process affecting the organism or the consequences of effects on the organism (Selye, 1950, 1976) has been confusing. Stress has been limited to one kind of physiological response mechanism, or to mental rather than physiological responses or has been regarded as a much more wide ranging phenomenon. A definition of stress as just a stimulation or an event which elicits adrenal cortex activity is of no scientific or practical value (Mason, 1971; Broom, 2001c). A precise criterion for what is adverse for an animal is difficult to find but one indicator is whether there is, or is likely to be, an effect on biological fitness. *Stress can be defined as an environmental effect on an individual which over-taxes its control systems and reduces its fitness or seems likely to do so* (Broom, 1983; 2001a; Broom and Johnson, 2000; Broom and Fraser, 2007). Using this definition, the relationship between stress and welfare is very clear. Firstly, whilst welfare refers to a range in the state of the animal from very good to very poor, whenever there is stress, welfare is poor. Secondly, stress refers only to situations where there is failure to cope but poor welfare refers to the state of the animal both when there is failure to cope and when the individual is having difficulty in coping. It is very important that this latter kind of poor welfare, as well as the occasions when an animal is stressed, is included as part of poor welfare. For instance, if a person is severely depressed or if an individual has a debilitating disease but there is complete recovery with no long term effects on fitness then it would still be appropriate to say that the welfare of the individuals was poor at the time of the depression or disease.

5. Welfare and health

The word 'health', like 'welfare', can be qualified by 'good' or 'poor' and varies over a range. However, health refers to the state of body systems, including those in the brain, which combat pathogens, tissue damage or physiological disorder.

Health may be defined as an animal's state as regards its attempts to cope with pathology (Broom, 2000). In this statement, animals include humans. The meaning of pathology is discussed at length by Broom and Kirkden (2004) and Broom (2006a).

Welfare is a broader term than health, covering all aspects of coping with the environment and taking account of a wider range of feelings and other coping mechanisms than those which affect health, especially at the positive end of the scale. Although people regularly refer to poor health, they sometimes use the word to mean absence of illness or injury in the same way that people refer to welfare when they mean good welfare. However the precise and scientific use of both health and welfare must refer to states varying from very good to very poor. 'Health' is encompassed within the term 'welfare', and indeed is a very important part of welfare.

Health is a part of welfare and hence disease always has some adverse effect on welfare (Broom and Corke, 2002). There can also be effects in the other direction because specific aspects of health may be made worse when welfare in general is poor (Broom, 1988b). These relationships are summarised in Figure 1.

The sequence could start with infectious disease which then causes poor welfare. Alternatively, inadequate housing conditions could lead to poor welfare and hence to increased disease susceptibility. If animals became diseased as a consequence, this would result in worse welfare than that caused directly by the housing conditions.

When an animal's health is poor, so is its welfare, but poor welfare does not always imply poor health. There are many circumstances where behavioural or physiological coping mechanisms are activated, indicating that welfare is poor, but the animal's health remains good. These include: situations where the coping mechanisms are successful, such as when body temperature is maintained despite extreme ambient temperatures; circumstances where failure to cope has consequences for psychological, but not physical, stability, such as in the development of non-injurious pathological behaviours; and where detrimental effects upon physical stability are compensated for by management practices, such as the routine use of antibiotics.

There are some indicators of poor welfare which are classified as pathology and, as such, will also indicate poor health. These include body damage and infectious disease. The prevention of normal physiological processes and anatomical development will also indicate poor health, where these phenomena can be shown to be symptoms of an infectious, metabolic or nutritional disease. Mortality rate is usually also an indicator of welfare in general and health in particular in the individuals in a population.

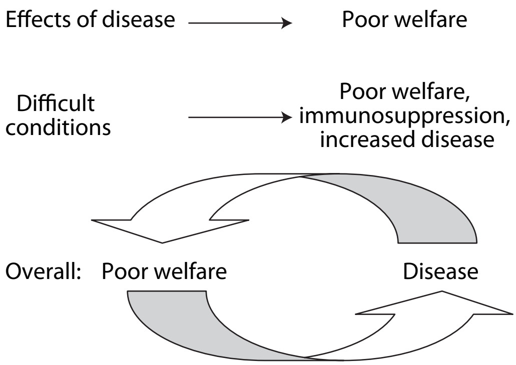

Figure 1. Relationship between welfare and health.

When animals are close to death, their welfare including their health will often be very poor.

Since health is a part of welfare, it is incorrect to refer to health and welfare as if these were separate non-overlapping concepts (Broom, 2001a). Hence, in the preamble of the Council of Europe Recommendations on pigs there is reference to 'requirements for good welfare including good health'. When referring to developments in breeding and biotechnology, it is said that these 'shall not adversely affect the welfare, including especially the health of pigs'.

The general conclusions about the inter-relationships between welfare improvement attempts and disease are: firstly that disease is an aspect of poor welfare and many actions will be of benefit in both respects. Secondly, the possible trade off between reduced immunosuppression and increased disease transmission risk should be carefully considered in all attempts to improve welfare. Thirdly, there are differences between production- or system-related diseases and dangerous infectious diseases. Whilst we have quite a lot of information about the former, the latter should also be borne in mind when developing new systems for housing and managing animals. Our overall aim should be to improve welfare in total and we should always include consideration of the effects on individuals of any disease which they might contract (Broom, 1992)

6. Welfare and pain

The pain system and responses to pain are part of the repertoire used by animals, including man, to help them to cope with adversity during life. Pain is clearly an important part of welfare. It can be an indicator that the environment outside the control systems in the brain is having an impact such that, the individual is having difficulty in coping. Pain may also indicate that there is likely to be a failure to cope in the long term.

Pain is defined here as an aversive sensation and a feeling associated with actual or potential tissue damage (Broom, 2001b). This is an improvement on a previous definition used by the author and is similar to that of the International Association for the Study of Pain (Iggo, 1985): 'Pain is an unpleasant sensory or emotional experience associated with actual or potential tissue damage, or described in terms of such damage'. One difference from Iggo's definition is that 'aversive' is used instead of 'unpleasant' because aversion is more readily recognised and assessed than unpleasantness, particularly in non-human species. Aversive behaviour is not always shown and sometimes the feeling of aversion is overcome in the individuals concerned, for example in those who choose to inflict pain on themselves, but the aversion and hence the pain are still present. A second difference is the reference to feelings rather than emotion because feeling implies some degree of awareness. An emotion is a physiologically describable electrical and neurochemical state of particular regions of the brain which may result in other changes in the brain, hormone release or other peripheral changes but which need not involve awareness. (Broom, 1998; Sommerville and Broom, 1998). Hence an emotion may involve feelings but need not do so, it is better to refer to feelings when defining pain.

The third difference from Iggo's definition is that pain is a 'sensation *and* a feeling' rather than a 'sensory *or* emotional experience' because a sensory experience could be as little as a sensory input that reaches a low level in the brain and can be remembered very briefly. Most authors (Blood *et al.*, 1988) consider that a feeling is involved in pain and that input which does not involve some awareness is not pain. The fourth difference is that Iggo refers to the possibility of pain being described in terms of damage. Because damage can do no more than indicate the likelihood of pain, this is not included in the definition used here.

In order to feel pain, animals need to have receptor cells in appropriate places in the body, peripheral and central neural pathways with neuro-transmitters and adequate processing centres in the brain. The pain system would be expected to have links between these brain centres and an output system which can initiate a behavioural or other response. Acute pain could result in behavioural avoidance, repeated risk of acute pain could result in learning so that potential damage could be avoided and chronic pain could result in suppression of activity and behaviour which ameliorates adverse effects. A mechanism for switching off the feeling of pain such as that mediated by endorphins and other opioids would also be expected because if pain has a great effect on behaviour, such an effect would sometimes be dangerous. All vertebrate animals have the general characteristics of pain systems detailed in Table 1.

Table 1. Characteristics of pain systems (after Broom, 2001b).

1. Long-lasting output from specialised nociceptors with high thresholds and with little adaptation to repeated or continuing stimulation.
2. Output from other highly stimulated receptors.
3. Sensitisation of nociceptors (threshold lowered) possible.
4. Neurotransmitters such as substance P and glutamate.
5. Possibility for rapid response, e.g. by reflex.
6. Behaviour change in response to pain.
7. Learning to minimise future pain.
8. Involvement of some phylogenetically old parts of brain.

7. Welfare concepts in relation to assessment

Most welfare indicators will help to pinpoint the state of the animal wherever it is on the scale from very good to very poor (Broom, 1988a). Some measures are most relevant to short-term problems, such as those associated with human handling or a brief period of adverse physical conditions, whereas others are more appropriate to long-term problems. Tests of avoidance and positive preference help in the design of better conditions and procedures for pigs.

In all welfare assessment it is necessary to take account of individual variation in attempts to cope with adversity and in the effects which adversity has on the animal. When pigs have been confined in stalls or tethers for some time, a proportion of individuals show high levels of stereotypies whilst others are very inactive and unresponsive (Broom, 1987). There may also be a change with time spent in the condition in the amount and type of abnormal behaviour shown (Cronin and Wiepkema, 1984). In rats, mice and tree shrews it is known that different physiological and behavioural responses are shown by an individual confined with an aggressor and these responses have been categorised as active and passive coping (Koolhaas *et al.*, 1983; Von Holst, 1986; Benus, 1988). Active animals fight vigorously whereas passive animals submit. A study of the strategies adopted by gilts in a competitive social situation showed that some sows were aggressive and successful, a second category of animals defended vigorously if attacked whilst a third category of sows avoided social confrontation if possible. These categories of animals differed in their adrenal responses and in reproductive success (Mendl *et al.*, 1992). As a result of differences in the extent of different physiological and behavioural responses to problems it is necessary that any assessment of welfare should include a wide range of measures. Our knowledge of how the various measurements combine to indicate the severity of the problem must also be improved.

The assessment of welfare should be carried out in an objective way, taking no account of any ethical questions about the systems, practices or conditions for individuals which are being compared (Broom and Johnson, 2000). Once the scientific evidence about welfare has been obtained, ethical decisions can be taken.

Much of the evidence used in welfare assessment indicates the extent of the problems of individuals but it is also important to recognise and assess good welfare, i.e. happiness, contentment, control of interactions with the environment and possibilities to exploit abilities. We should try to assess the specific functioning of the brain when welfare is good in humans and other animals (Broom and Zanella, 2004); the methods of recognising when welfare is, or is likely to be, good; and the factors which contribute to good welfare in man and other species.

Good welfare in general, and a positive status in each of the various coping systems, should have effects which are a part of a positive reinforcement system, just as poor welfare is associated with various negative reinforcers. There should be various recognisable effects on individuals of good welfare. We need to identify these so that the assessment of welfare is as effective at the good end of the range as at the bad end.

Each assessment of welfare for a human or other animal will pertain to single individual and to a particular time range. In the overall assessment of the impact of a condition or treatment on an individual, a very brief period of a certain degree of good or poor welfare is not the same as a prolonged period. However, a simple multiplicative function of maximum degree and duration is often not sufficient because the most severe effect of poor welfare may be brief whilst there is a more prolonged milder effect. If there is a net effect of poor welfare and the severity of the poor welfare is plotted against time (Figure 2), the best overall assessment of welfare for that individual animal is the area under the curve thus produced (Broom, 2001c).

A subject which is ethical rather than scientific is the policy which should be adopted in relation to the number of individuals affected. When many subjects are used in a study of the effects of a condition or treatment on welfare, a larger number of individuals with poor welfare overall indicates a greater problem than a smaller number. Hence if a million broiler chickens have a problem, this is more important than one thousand chickens or one thousand cows or dogs with the same degree of problem. However, most people would consider that any individual whose welfare is very poor merits consideration so decisions about policy are not just taken on the basis of the overall severity of the problem multiplied by the numbers of individuals concerned (Broom, 2001c).

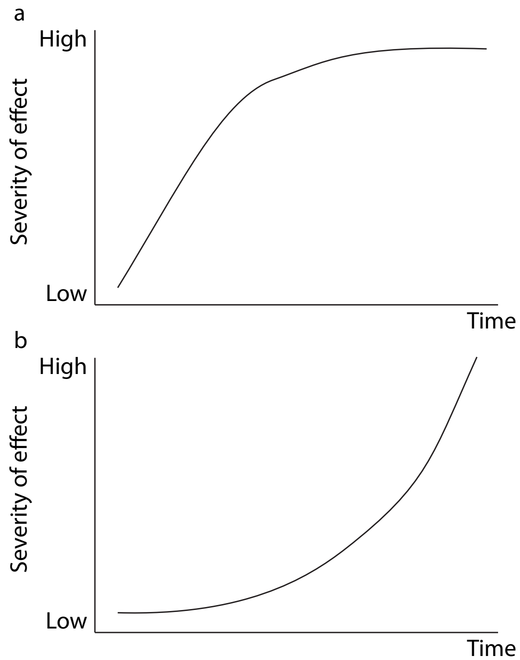

Figure 2. The overall effect on welfare up to a certain time is the area under the curve when severity of effect is plotted against time. This is greater in (a) than in (b) (adapted from Broom, 2001c).

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Chapter 2. Assessment of pig welfare

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Abstract

Assessment of welfare relies upon the analysis of the interaction between the animals and their environment, including behaviour, biological changes among which the hypothalamic-pituitary-adrenocortical axis and the autonomic nervous system play an important role, and their consequences on production traits and possibly health status. Most of these measures derive from the study of emotions/stress/adaptation psychophysiology and physiopathology. Although immediate responses to acute stimulations have been extensively studied, long-term changes under chronic challenge or continued pressure from the environment are much more difficult to analyse and should be distinguished from spontaneous individual variations such as those influenced by genetic factors. On the other hand, none of these processes is specifically related to welfare, and experimental results should be interpreted with caution in the context of the physiological mechanisms of homeostasis. Comparison of data obtained with different approaches is important to gain a better understanding of the perception of the environment by the animal, and the consequences on its welfare.

Keywords: stress, hypothalamic-pituitary-adrenocortical axis, autonomic nervous system, behaviour, adaptation, swine, welfare

1. Introduction

Beyond a large diversity of concepts, welfare refers principally to the subjective psychological state of the individual, as related to its internal and external environment (Fraser, 1999; Rushen, 2003; Broom, in this book). Since we are not yet at the stage of being able to read directly animals' feelings and emotions, we try to infer those from measurable indices that we know or suppose to be related to them. Most of these measures – including behaviour, biology, production traits and pathology – derive from the study of emotions/stress/adaptation psychophysiology and physiopathology (Dantzer and Mormède, 1983). I do not intend to write an exhaustive review of the abundant literature available on this topic, but rather give a personal view of the limitations of these approaches and the challenges faced by researchers in future investigations. Comments and discussions will focus mostly on four major issues:

a. The autonomic nervous system (ANS), (Cannon, 1935) and the hypothalamic-pituitary-adrenocortical (HPA) axis (Selye, 1936) have the front of the stage in stress studies (Mormède, 1995). However, these neuroendocrine systems are primarily involved in metabolic homeostasis and particularly in the regulation of energy fluxes (Dallman *et al.*, 1995). In a teleological perspective, the reason why these systems are activated by stressors is that they are able to produce energetic metabolites either from energy storage tissues (the ANS mobilises fat from adipose tissues and glycogen from liver) or by transformation of proteins into energetic metabolites (neoglucogenesis enhanced by glucocorticoid hormones). This energy supply is used by the defense mechanisms to cope with the stressor. Consequently, any change in HPA axis or ANS functional parameter is not necessarily the response to a stressful stimulus, but can reflect their involvement in homeostatic metabolic processes. The best example is the increase of cortisol levels induced by meals that are not usually considered as stressors. Furthermore, metabolic adaptive changes do not necessarily require activation of these systems, but can sometimes shut them down, depending upon the specific demands of the situation. For instance the response of the ANS to early weaning in pigs is an inhibition that can bee seen by the reduction of catecholamine levels in urine (Hay *et al.*, 2001). This is an energy saving mechanism adapted to the deficit resulting from weaning-induced starvation. These metabolic influences on neuroendocrine changes must be taken into consideration when interpreting experimental data.
b. The second point of discussion is the duration of the stimulus. This dimension of the response plays a pivotal conceptual role in the 'general adaptation syndrome' as described by Selye, with the three successive phases, alarm, resistance and exhaustion (Selye, 1956). The biological responses to acute challenges (such as delivery, castration, weaning, mixing of animals from different social groups, restraint, transportation, slaughter) have been studied extensively and, like most stressors, activate biological stress systems in a more or less standardised manner (alarm phase). This common pattern of response is at the origin of the stress concept that was defined par Selye as the 'non-specific response of the body to any demand made upon it' (Selye, 1973). Note however that this non-specificity is mostly the result of the uniqueness of the response of the HPA axis, i.e. an increase in circulating cortisol levels that is exquisitely sensitive to 'any demand', whatever its nature and intensity. However, if the stimulus is maintained for some time blood cortisol returns to control levels even if the sustained activation of the HPA axis can be detected by different approaches like dynamic testing. Since many factors challenging animal welfare are long lasting – this is the case for most influences from the physical and social environment of the animals – more attention should be given to the exploration of chronic readjustments of adaptation mechanisms (resistance phase or allostasis) (McEwen, 1998).

c. The third issue is the huge individual variability seen in the basic functioning of adaptation mechanisms and in their responses to environmental challenges. This variability has a multiple origin, genetic, developmental, and experiential. Although it may not be of primary importance in longitudinal protocols with the same animals studied in basal conditions and then submitted to control or experimental situation, it has to be taken into consideration in field studies in which the history of the animal is not readily available.
d. The fourth issue is the multivariate nature of the interaction of the individual with its environment that we have to keep in mind when assessing welfare.

2. Neuroendocrine systems

2.1. The hypothalamic-pituitary-adrenocortical axis

2.1.1. General organisation

The HPA axis has the classical architecture of the major neuroendocrine systems (Mormède, 1995). The main active hormone of the axis in pigs is cortisol, a cholesterol-derived steroid synthesised in the fascicular zone of the adrenal cortex under the control of the pituitary hormone ACTH (adrenocorticotropic hormone) and released in the general circulation to reach its receptors in tissues. ACTH is synthesised by specialised cells of the anterior pituitary gland (corticotrophs) and its release is triggered by the coordinated action of two neuropeptides, the corticotropin-releasing hormone (CRH) and vasopressin (AVP), that are synthesised in specialised neurons of the paraventricular nucleus of the hypothalamus (PVN) and released in the capillary bed of the median eminence from where they reach the pituitary directly via the hypothalamic-pituitary portal circulation. The PVN receives numerous inputs from other hypothalamic nuclei (these inputs carry metabolic and nycthemeral signals), from the brain stem (in relation with neural inputs from the periphery), from the subfornical organ (that monitors blood plasma composition) and from the limbic system (that generates signals related to the emotional state). This multiplicity of signals converging to the PVN explains the sensitivity of the HPA axis to a wide range of stimuli from both internal and external origin. On the other hand, cortisol exerts a negative feedback on the axis by acting on the pituitary corticotrophs, the PVN and higher levels in the central nervous system. This feedback action of cortisol participates in the return of the HPA axis activity to basal levels after stimulation.

2.1.2. Physiology of the HPA axis

Due to its lipophilic nature, most circulating cortisol (approx. 90%) is bound to proteins, principally albumin and corticosteroid-binding globulin (CBG), a specialised glycoprotein that binds cortisol with high affinity, and regulates its bioavailability (Gayrard *et al.*, 1996). The free fraction can easily cross biologic membranes (that are permeable to lipid-soluble compounds), including the blood-brain barrier and cellular membranes. Cortisol interacts with intracellular receptors – mineralocorticoid receptors (MR) and glucocorticoid receptors (GR) – that, upon activation by their ligand, translocate to the cell nucleus to activate or inhibit gene expression (transcription factors) (Perreau *et al.*, 1999). In the periphery, aldosterone is the primary hormone activating the mineralocorticoid receptor. Aldosterone is released by the adrenal cortex under the influence of the renin-angiotensin system, but also ACTH. In the, tissues involved in water and electrolytes metabolism, and responsive to aldosterone (kidney, salivary glands and colon), the mineralocorticoid receptor is protected from cortisol by a specific enzyme, the 11β-hydroxysteroid dehydrogenase (11βHSD) that metabolises cortisol into its inactive derivative cortisone (Stewart and Krozowski, 1999).

Detailed information on the metabolic effects of cortisol that are numerous and complex can be found in Sapolsky *et al.* (2000). Altogether, cortisol has catabolic activity – proteolytic and lipolytic – in peripheral tissues and anabolic activity in liver, including gluconeogenesis and protein synthesis (McMahon *et al.*, 1988). Since cortisol also reduces the entrance of glucose into cells, it increases blood glucose and insulin secretion (the latter is also increased by an action of cortisol on ANS function in the hypothalamus), leading to the storage of energy as fat in the adipose tissue, if the energy is not used in the stress response, by behavioural adjustments for instance. The net effect is an increase of fat depots at the expense of tissue proteins (e.g. from muscle, bone) that may not be too interesting in the long range, at least for the efficiency of pork production (Devenport *et al.*, 1989). Cortisol also increases feed intake by an action on the brain so that, as it is frequently the case in homeostatic regulations, the increase of energy availability is a coordinated process via peripheral and central mechanisms (Tempel and Leibowitz, 1994).

The activity of the HPA axis is highly variable. First, the secretion of cortisol is pulsatile, with a periodicity of approx. 90 minutes. Although this feature is well documented in several species like humans (Follenius *et al.*, 1987), bovine (Thun *et al.*, 1981) or sheep (Fulkerson and Tang, 1979), it has not been described in pigs, and we got no experimental evidence that it is indeed the case. The second source of variability is the diurnal cycle that is genetically determined and synchronised by light. In diurnal species (including pigs), the peak activity can be measured in the morning and the trough during the evening and the night (Favre and Moatti, 1977; Ruis *et al.*, 1997; Désautés *et al.*, 1999; Hay *et al.*, 2000). This is indeed an important factor to be taken into consideration in experimental and clinical studies, since the difference between morning and evening levels of cortisol in plasma, saliva, and urine – just to cite the most important biological fluids used in these studies – is very large (Figures 1 and 2). The third source of variability comes from feed intake that activates the HPA axis. Surprisingly enough, although the meal-induced release of cortisol has been described in humans many years ago (Follenius *et al.*, 1982) and confirmed in several species (Honma *et al.*, 1984; Garcia-Belenguer *et al.*, 1993), it has not been specifically investigated in pigs, but it can be found in experimental data (Ruis *et al.*, 1997; Hay *et al.*, 2000; Geverink *et al.*, 2003; Figures 1 and 2).

2.1.3. Response to acute stimulations

The acute response of the HPA axis can be studied by monitoring the release of ACTH and cortisol as well as the effects of cortisol such as the increase of blood glucose levels or the changes in leucocytes counts. Since the assay of plasma cortisol levels is easily feasible in any biology laboratory, it has become the golden standard to evaluate the stress response and plasma cortisol levels are frequently equated to the level of stress, explicitly or implicitly. Several comments must be made to replace blood cortisol levels more accurately among the different measures available to assess pig welfare:

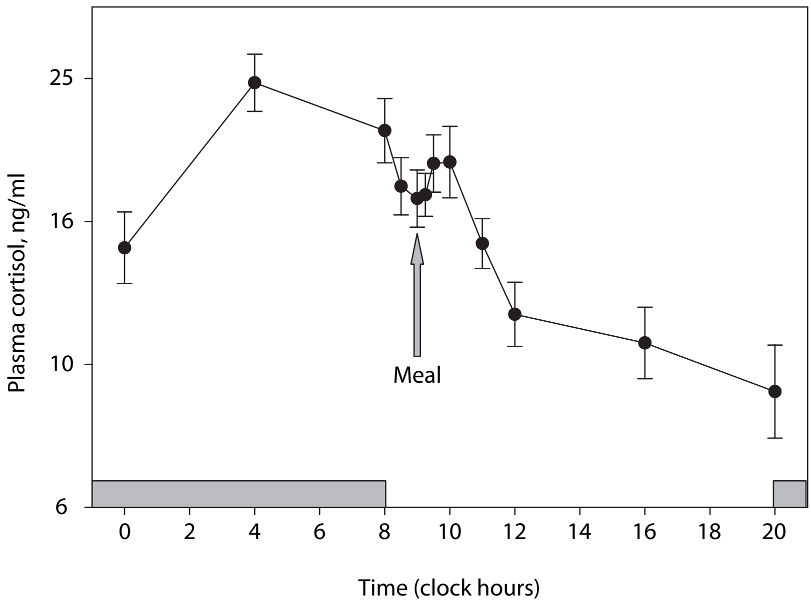

Figure 1. Plasma cortisol levels measured in pregnant sows fitted with an indwelling jugular catheter. The immediate increase of cortisol levels following the single food distribution is clearly visible, followed by a profound and long-lasting decrease (Hay et al.*, 2000).*

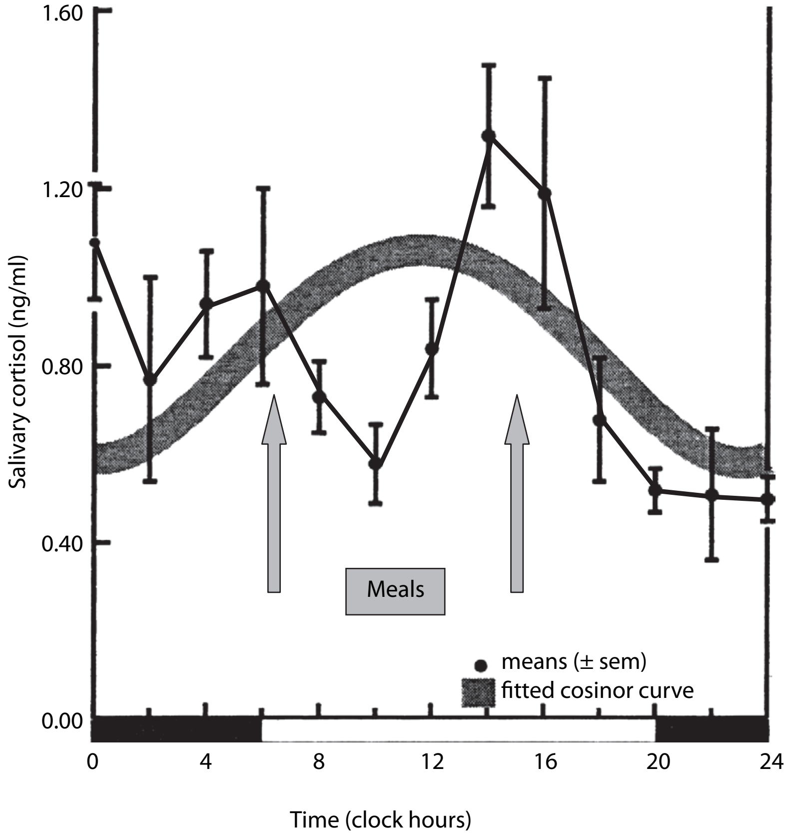

Figure 2. Salivary cortisol levels under basal conditions, and fitted cosine curves (shaded lines), in 16-week old growing pigs. Arrows show the time of food distribution (adapted from Ruis et al.*, 1997).*

a. The knowledge of the HPA axis physiology shows that cortisol levels may be increased by several environmental factors, such as meals or physical exercise (Brandenberger *et al.*, 1984; Luger *et al.*, 1988), that are not necessarily considered as stress factors. Salivary cortisol levels are also higher in pigs raised in an enriched (vs. barren) environment (De Jong *et al.*, 1998, 2000; de Groot *et al.*, 2000). Therefore, any change measured in cortisol levels should be interpreted in the context of its physiological roles.
b. Cortisol levels are exquisitely sensitive to many environmental factors. The mere exposition of an animal to a novel environment is sufficient to increase blood cortisol to its highest possible levels (Mormède and Dantzer, 1978). Although there is no semantic problem to qualify novel environment exposure as a stress factor – and indeed any novel stimulus is a potential challenge – it does not necessarily

compromise welfare, and many would agree that novelty frequently adds salience to life, especially in a generally boring environment as offered by intensive farming. One dimension of the response that cortisol levels do not evaluate correctly is its intensity. Dose-response studies show that the increase of plasma ACTH levels is much more graded with stimulus intensity, as mimicked experimentally by injections of CRH at increasing doses (Oelkers *et al.*, 1988, in humans; Zhang *et al.*, 1990, in pigs; Veissier *et al.*, 1999, in calves). This reflects both the extreme sensitivity of the adrenal cortex to detect and amplify the ACTH signal, and the rapid saturation of the response with increasing ACTH concentrations. Therefore, measuring ACTH and cortisol in the same plasma samples allows a better coverage of the whole range of response intensities that should help in the evaluation of stimulus strength, an important dimension in the assessment of welfare.

c. The use of blood samples to assess HPA axis activity is not without problem, especially in pigs from which blood is difficult to collect without physical contact with the animal and in most instances, without a strong restraint that can by itself activate the HPA axis, not only in the handled animal, but also in the pen- and room-mates. Alternative biological fluids have therefore been considered. Saliva can be collected easily since pigs are very keen to chew anything including cotton buds out of which saliva can be obtained. Saliva being primarily an ultra-filtrate of blood plasma, salivary cortisol reflects the free fraction of plasma cortisol after metabolism by 11βHSD that is highly active in the salivary glands. Therefore it follows the same pattern as plasma cortisol, but at much lower levels (approx. 10%) that require a very sensitive and specific (due to the presence of cortisone) assay (Cook *et al.*, 1996). On the other hand, the interest of saliva to measure other parameters related to stress and welfare processes is limited. Catecholamine contents do not reflect general activity of the ANS but rather local regulation. Another interesting fluid is urine that is a major excretory pathway of cortisol and its metabolites (including cortisone), and many other biological products. The first interest of using urine is that it can be collected with minimal trouble to the animal, although the investigator is dependent upon its good will to obtain urine when spontaneously voided. A few tricks are available or under evaluation to help Mother Nature, such as dipping the paws of piglets in water to initiate urination. An important characteristic of urine is that it integrates the excretion of biological compounds over the time between two successive emissions. This is eventually a handicap to study short duration processes but is an invaluable help when studying long term changes or individual differences in basal activity of the HPA axis, since it removes short term variations that usually introduce noise into measures made in plasma or saliva. Finally, many other parameters can be measured in urine, including catecholamines and their metabolites, which allows a more comprehensive investigation of the neuroendocrine adaptive processes. We have developed the analytical techniques to measure corticosteroids and catecholamines in pig urine samples (Hay and Mormède, 1997a,b) and these techniques have been validated in a number of studies aiming at the study of genetic variation and/or stress studies (Hay and Mormède, 1998; Hay *et al.*, 2000, 2001; Mormède *et al.*, 2004; Foury *et al.*, 2005a). More work is under way to compare different breeding systems (Pol *et al.*, 2002; Foury *et al.*, 2005b; Colson *et al.*, 2006a,b; Lebret *et al.*, 2006) and it should be extended to epidemiological studies in relationships with other parameters to be discussed later.

2.1.4. Chronic changes

Even if the triggering stimulus is maintained, plasma cortisol levels usually decline after the acute response. This does not mean that the HPA axis is back to basal functioning since several indices show that the activity of the system has changed. Each level of the axis (hypothalamus, anterior pituitary, adrenal cortex) is subjected to opposite influences, trophic via their respective stimulating inputs (such as CRH to the pituitary or ACTH to the adrenal cortex) and inhibitory via corticosteroid hormones. Among the changes induced by chronic activation of the HPA axis and well documented in laboratory animals (Gertz *et al.*, 1987; Mormède *et al.*, 1990), we can cite weight loss (the result of the catabolic effect of cortisol and catecholamines), the shrinkage of thymus (a tissue rich in MR and a sensitive indicator of chronic cortisol action), the proliferation of the corticotrope cells in the anterior pituitary (a trophic effect of CRH), an inhibition of ACTH synthesis (by cortisol) and a reduction of the feedback affect of GR agonists on ACTH release, an increase of the size of the adrenal glands and of the response of the adrenals to ACTH (a trophic effect of ACTH). This resetting of the HPA axis at a different level of activity, that Selye (1956) described as the stage of resistance, is also known as allostasis (McEwen, 1998), and specific protocols are necessary to demonstrate these changes induced by a sustained activation of the HPA axis.

a. Plasma or salivary cortisol levels are not very informative. Although they can be slightly elevated over basal levels, these changes are difficult to detect without catheterisation and/or multiple sampling, as compared to spontaneous variations or the effects of blood sampling itself (Barnett *et al.*, 1988). Furthermore, the effect of stress is not constant over the day, and increased cortisol levels have been seen mostly at night, when they are usually low (Barnett *et al.*, 1981; Janssens *et al.*, 1995b). Measurement of cortisol levels in urine may be more sensitive to detect these small changes since rapid variations are buffered over time, but this hypothesis has still to be documented.
b. The best studied change is the sensitisation of the adrenal cortex response to ACTH by chronic stimulation. Prolonged chain tethering, confinement, high densities increase the release of cortisol induced by a standard dose of ACTH (Rampacek *et al.*, 1984; Meunier-Salaün *et al.*, 1987; Von Borell and Ladewig, 1989; Janssens *et*

al., 1994). Similarly, the cortisol response to various stimuli acting at higher levels of the axis is also increased (CRH, insulin-induced hypoglycemia for instance, Figure 3), although the ACTH response is frequently lowered or unchanged, due to the chronically enhanced feedback of cortisol on the pituitary (Janssens *et al.*, 1995a).

c. Another classical test is named the dexamethasone suppression test (DST) and was developed initially to explore the HPA axis function in depressive patients (Carroll *et al.*, 1981). Dexamethasone is a synthetic compound with glucocorticoid activity and inhibits strongly the secretion of cortisol by acting on pituitary ACTH release. Since the feedback activity of glucocorticosteroids is reduced when the HPA axis is chronically activated, such as in depressed patients, it 'escapes' dexamethasone suppression. It was shown to be the case in pigs when space was restricted (Meunier-Salaün *et al.*, 1987).

When the increased activity of the HPA axis is documented, we still have to interpret the results in the context of environmental influences on HPA axis activity and individual differences, especially when no longitudinal data are available from the same animals, such as in epidemiological studies. First, environmental factors may have a strong influence on HPA axis activity, as described earlier. The study of the influence of temperature and humidity is rather impressive in this respect (Marple *et al.*, 1972; Figure 4). Second, large individual variations in HPA axis activity have been documented in pigs. In a pioneering series of studies, Hennessy and collaborators have shown that the adrenal response to ACTH is an individual characteristic, reproducible across successive testing, and inheritable (Hennessy *et al.*, 1988; Zhang *et al.*, 1990, 1992). The intensity of the adrenal response to ACTH was found to be negatively correlated with body weight and growth rate (Hennessy and Jackson, 1987). Several lines of evidence confirm the genetic influences on HPA axis activity. Large differences can be found between porcine breeds (Bergeron *et al.*, 1996; Désautés *et al.*, 1997; Weiler *et al.*, 1998; Mormède *et al.*, 2004) and divergent genetic selection on the basis of the HPA axis response to stress could be made in different species (Edens and Siegel, 1975; Pottinger and Carrick, 2001), but no such data are available yet in pigs. Individual variations can also arise from environmental influences, either during pregnancy and early post-natal life or as a result of previous experience. These early influences have been extensively studied in laboratory animals and offer new approaches to control for emotional reactivity, including neuroendocrine responses (Meaney *et al.*, 1991) but more studies are necessary to validate these findings in pigs (Weaver *et al.*, 2000; Otten *et al.*, 2001; Tuchscherer *et al.*, 2002).

In conclusion, the HPA axis is primarily involved in the regulation of energy fluxes in the body, and is therefore sensitive to various environmental stimuli challenging the energy balance of the body, such as nycthemeral influences, feed intake and

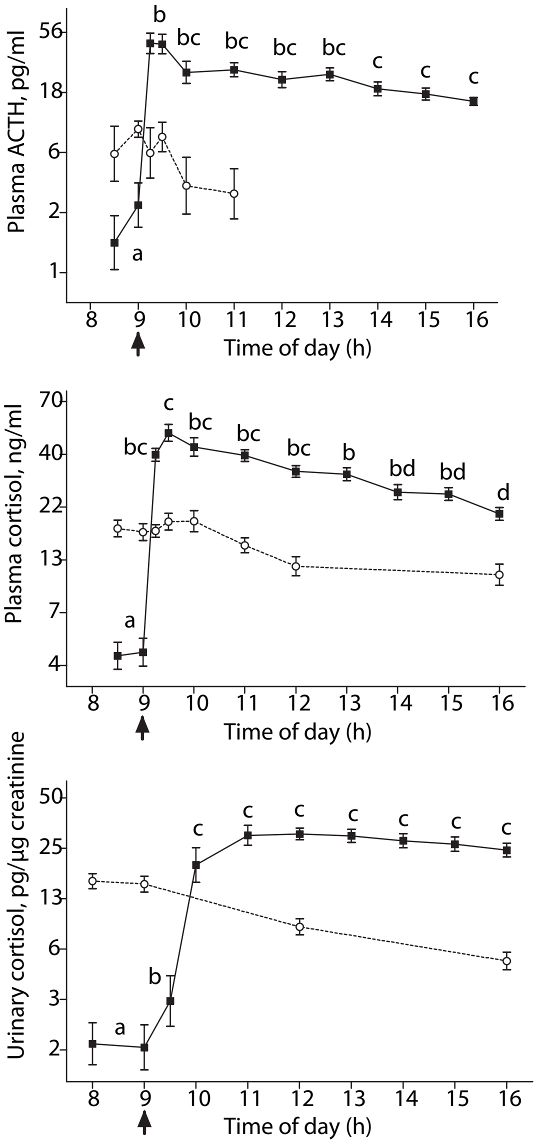

Figure 3. Dexamethasone suppression test and corticotrophin-releasing hormone challenge in pregnant sows. Dexamethasone (20 µg/kg) was injected i.v. at 20h00 and CRH (1 µg/kg i.v.) the next morning at 09h00 (arrow). Blood was taken from a jugular catheter at regular intervals to measure ACTH and cortisol levels in plasma. Urine was continuously collected for successive 1-hr periods to measure cortisol and creatinine. Control values measured on the previous day are shown with empty circles. Suppression of HPA axis is visible at the first two time points and CRH induces a strong activation of ACTH and cortisol secretion (from Hay et al.*, 2000).*

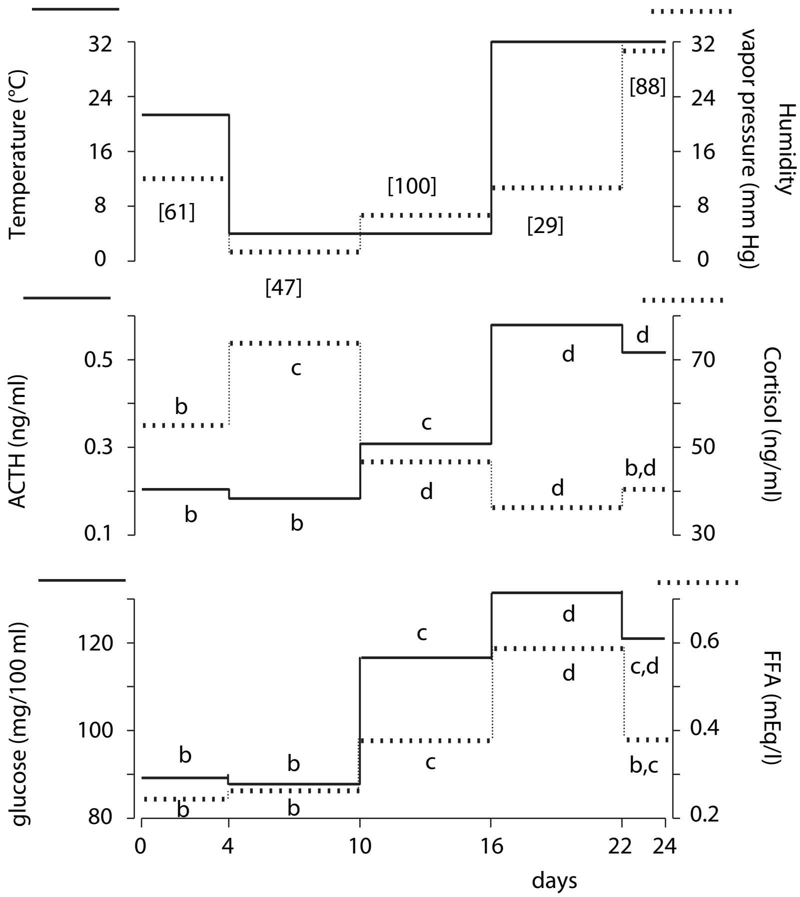

Figure 4. Effects of humidity and temperature on porcine plasma cortisol, ACTH and metabolite levels (data from Marple et al.*, 1972). Data were obtained from eight gilts (40-45 kg) kept in psychrometric chambers and fitted with intravenous catheters. Blood was collected twice daily. The inverse changes of ACTH and cortisol levels suggest that temperature and humidity affect principally the adrenal sensitivity to ACTH. Changes in glucose and free fatty acid levels suggest a participation of the ANS in these effects. Relative humidity is given in brackets. Means with different letters are significantly different (P< 0.05).*

temperature regulation. Furthermore, plasma cortisol levels are exquisitely sensitive to a whole range of stimuli, which do not need to be intense to maximally activate cortisol release, and altogether known as stressors. Therefore, monitoring plasma cortisol levels may give valuable information about the status of the animal with regard to its internal and external environment but must be interpreted with caution in terms of welfare. For long lasting stimulations, dynamic testing of the HPA axis (stimulation or suppression tests) are necessary to demonstrate the resetting of the system as an adaptation to sustained stimulation, and the data have to be interpreted in the context of environmental influences and individual variation of genetic or acquired origin.

2.2. The autonomic nervous system

2.2.1. General organisation

The ANS regulates the function of all the internal organs of the body including the cardiovascular, respiratory and digestive systems, and energy fluxes. In stress responses, the orthosympathetic part (catecholaminergic) of the system is primarily involved, although the parasympathetic (cholinergic) part may also be activated, for instance in the effect of stress on the digestive tract. Noradrenaline is released at the nerve endings of the sympathetic nervous system in the target organs, and both adrenaline and noradrenaline are released in the general circulation from the medullary part of adrenal glands. The differential activity of both catecholamines on their receptors and the differential distribution of the different receptor types and subtypes in tissues shape the specificity of their actions. A comprehensive understanding of the role of the ANS in adaptation/stress processes can be found in the cornerstone paper of Walter B. Cannon published in 1935. As a response to cold for instance, noradrenaline is preferentially released. It induces peripheral vasoconstriction (energy saving mechanism) and energy mobilisation, primarily from fat tissues. As a response to hypoglycemia on the other hand, adrenaline is released from the adrenal medulla as an effective mechanism to release glucose from liver and muscle glycogen. In case of acute, non specific challenge, such as in response to a strong emotional stimulus, a general activation occurs with an increase of blood pressure and cardiac pulse rate, respiratory frequency, energy mobilisation (with an increase in plasma free fatty acids and glucose).

2.2.2. Assessment of acute sympathetic responses

The release of catecholamines can be monitored directly from blood plasma (Fernández *et al.*, 1994, 1995). There are several limitations to this approach. Plasma levels of catecholamines are extremely sensitive to handling and the response can be detected within seconds, since the transmission of information, via neurons, is extremely fast, as compared to the HPA axis for instance (there is a time lag of approx. three minutes between stimulus application and the increase of cortisol levels in plasma). It is therefore illusory to measure basal catecholamine levels in plasma collected by direct venous puncture, and chronic catheter must be implanted for experimental purposes. On the other hand, the assay techniques to measure catecholamines in blood necessitate specific equipment and know-how and are not easily accessible to any biology laboratory. This approach is therefore limited to physiological investigations. Measuring catecholamines and their metabolites in urine (Hay and Mormède, 1997a) alleviates the problem of sample collection and rapid variations, but has obviously not the same time resolution. However, considering the time scale of the processes involved in welfare studies, this resolution may be largely sufficient.

In many cases, acute sympathetic responses have been studied by monitoring its physiological effects such as heart rate, blood pressure, plasma glucose and free fatty acid levels. The interest of such a parameter like heart rate is that it can be continuously monitored at distance by remote transmission of the physiological signal or stored by simple portable devices. It therefore allows a very sharp second to second analysis of the response to complex stimuli like transportation for instance. However, heart rate is susceptible not only to emotional/stress factors, but also to various influences like locomotion, physical activity or feed intake (Villé *et al.*, 1993; Talling *et al.*, 1996; Webster and Jones, 1998). Therefore data will have to be interpreted in this context. On the other hand, metabolic variables are frequently used in studies related to handling of animals before slaughter (mixing, transportation, duration and conditions of lairage, duration of feed withdrawal). Plasma glucose and free fatty acids levels reflect the balance between the mobilisation of energy stores and the use of energetic metabolites, primarily by muscular activity. Lactic acid levels reflect the intensity of anaerobic metabolism. These metabolic parameters are frequently associated with the measurement of circulating activity of enzymes of intracellular origin, such as transaminases and creatine kinase (CK) that reflect cell suffering. CK has been largely used to detect stress susceptibility in pigs (Guise *et al.*, 1998; Warriss *et al.*, 1998a,b; Pérez *et al.*, 2002; Foury *et al.*, 2005b; Faucitano and Geverink, in this book).

2.2.3. Metabolic adaptation, stress, welfare and ANS

The data collected recently in the study of the response of piglets to early weaning illustrates several critical aspects of the use of physiological parameters to assess welfare (Hay *et al.*, 2001). The selection of hyperprolific sows results sometimes in an excessive number of piglets that can be saved, when there is no possibility of adoption by other dams, by early weaning at 5 days after ingestion of colostrum. One question is whether this practice is acceptable in terms of animal welfare since these young animals are not prepared to ingest significant levels of solid feed before the 3rd-4th week when the piglet is fed by the dam. Indeed, early weaning induces an early and long-lasting reduction in growth rate. Urine was collected from the piglets before weaning and at regular intervals over the two following weeks. Cortisol levels were elevated in urine the day after weaning but were back to control levels at day 5 after weaning. This activation of the HPA axis by weaning has been shown in several studies using plasma cortisol levels, whatever the age at weaning. Since it is only short lasting, we could conclude that, although early weaning induces a typical stress response, stress is short lasting and the animal is adapted after a few days. However, the measurement of catecholamine levels in urine gives a completely different view of adaptation processes. Indeed, early weaning induces an early and profound reduction of the levels of noradrenaline, that do not return to control levels before the end of the second week after weaning, as well as a delayed (measurable on the ninth day after weaning) but sustained reduction of adrenaline levels. How can we interpret these changes? By considering the metabolic roles of catecholamines. As shown before, noradrenaline produces heat by burning lipids. The noradrenergic system is therefore activated by cold to keep core temperature constant, and by excess caloric intake to regulate body weight. In case of feed shortage, the switch off of the noradrenergic system is an energy saving mechanism (Stefanovic *et al.*, 1970). Indeed, the reduction of metabolic heat production is compensated for by behavioural adaptation mechanisms since the early weaned piglets spend more time under the heating lamp than control animals (Orgeur *et al.*, 2001). On the other hand, adrenaline is able to mobilise glycogen stores and its sustained release during the first days after weaning is therefore adapted to the reduction of feed intake in order to maintain blood glucose levels. What may be conclusions with regard to the assessment of welfare? That cortisol gives a limited and therefore biased view of adaptive processes. Although cortisol excretion levels were back to control levels a few days after early weaning, the profound and long lasting changes in catecholamine excretion levels are indicative of a sustained taxing of adaptive processes, primarily related to the deficit of feed intake. The reader is invited to read Mormède and Hay (2003) for a more complete discussion.

The second example illustrating the interest of monitoring the ANS via the measure of catecholamine excretion in urine comes from the study of breed differences in the response to preslaughter stress (Mormède *et al.*, 2004). Since this experiment was designed primarily to study molecular characteristics of muscles in relationship with meat quality, the animals were managed with as little stress as possible. They were not mixed from different pens, the truck was driven smoothly, and the animals were handled gently. Urine was collected on farm (basal conditions), upon the arrival in the slaughterhouse in the evening (after 10 hours of transportation from the breeding farm) and the next morning before slaughter. Data for the Large White and Duroc pigs are shown in Figure 5 and compared to the values measured in urine collected from the bladder after slaughter in a group of approx. 300 animals from an F2 intercross between these two breeds, handled and slaughtered in commercial conditions 50 km away from the breeding unit (Foury *et al.*, 2005a). First, these data illustrate the breed differences in neuroendocrine functioning (both basal and in response to stimulation). Second, although urinary cortisol levels are in the same range after transportation in optimal conditions and after slaughter of animals handled more conventionally, large

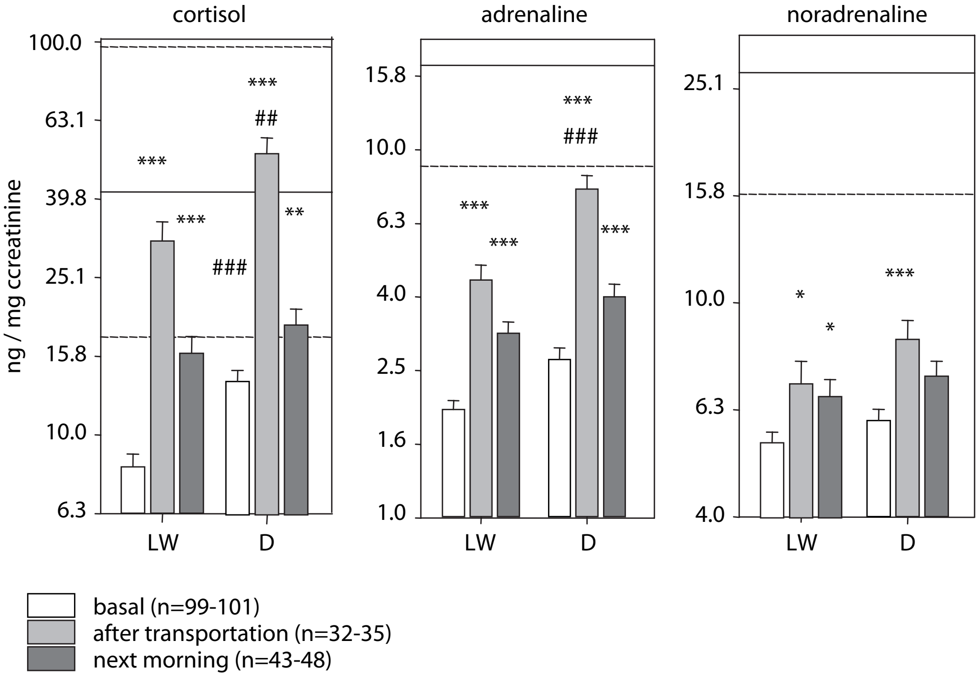

*Figure 5. Cortisol and catecholamine levels in urine, breed differences. Urine was collected when spontaneously voided (1) in the farm (basal levels), (2) at the arrival in the lairage area after c.a. 10 hrs of transportation, and (3) in the morning before slaughter after a full night of rest. Hormone levels were measured by HPLC after extraction, and expressed relative to creatinine levels to take into account urine dilution. Data were transformed into their logarithmic score before statistical analysis for normalisation of distributions. Differences between the first and subsequent sampling times within breed: * P < 0.05, ** P < 0.01, *** P < 0.001. Differences between breeds at the same sampling time: ## P < 0.01, ### P < 0.001. LW = Large White, D = Duroc. The horizontal lines give reference values (mean ± S.D.) measured in urine collected from the bladder of 302 pigs (F2 Duroc x LW) handled and slaughtered in commercial conditions for comparison.*

differences are measured for adrenaline and more so for noradrenaline that is hardly increased by smooth handling and transportation of the animals.

These two examples show that taking into consideration the ANS response to challenges widens our understanding of adaptive processes:

a. The importance of metabolic factors. Although we showed previously their influence in the regulation of HPA axis activity, they are even more important for the functioning of the ANS (see also Hay *et al.*, 2000, about the influence of meal). One noticeable point to stress out is the specificity of metabolic influences on adrenaline and noradrenaline. It shows that the ANS is not activated as a whole single system but differentially according to the specific action of adrenaline and noradrenaline.

b. The differential sensitivity of cortisol, adrenaline and noradrenaline as measures of stress. The experiment on transportation (Mormède *et al.*, 2004) confirms that the HPA axis is highly sensitive and does not discriminate stimuli with different intensity. The noradrenaline response appears to be the least sensitive, adrenaline being intermediate. Therefore monitoring the excretion of catecholamines gives not only qualitative but also quantitative information about the adaptive response.

2.2.4. Chronic changes

The knowledge of allostatic processes in the ANS is rather limited in pigs. A well-documented effect of chronic stress in laboratory animals is the increase of enzymatic activities in the synthetic pathway of catecholamines, including tyrosine hydroxylase, the first and limiting step, and PNMT (phenylethanolamine N-methyl transferase) that catalyses the transformation of noradrenaline into adrenaline in the adrenal medulla (Mormède *et al.*, 1990). A few studies only have been done in pigs (Stanton and Mueller, 1976; Roberts *et al.*, 1996). The study of heart rate variability is a possible approach to study sympathetic vs parasympathetic tone (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996; Villé *et al.*, 1993).

3. Behaviour

Behaviour is the primary way of interaction of the animal with its environment. Most physiological regulatory processes maintain homeostasis throughout coordinated behavioural and biological mechanisms. This is also the case for stress and adaptation processes (Dantzer and Mormède, 1983). Furthermore, the study of behaviour is not invasive, and can be achieved without introducing any trouble to the subjects; it usually necessitates a minimal equipment only (but experienced scientists); it has an excellent time resolution and nevertheless allows longitudinal studies; it may also by itself be a source of distress like in social and human-animal interactions or when behavioural needs cannot be satisfied. All these reasons have put forward the use of behaviour as the primary approach in welfare studies.

Behaviour is a sensitive index of the physiological status of the animal. For instance, the mere observation of the repartition of the pigs in the pen reflects the thermoregulatory status of the animals (Shao *et al.*, 1997), and therefore integrates a number of contributing factors related to the environment (temperature, humidity, air speed, nutritional level) and the animal (physiological status, basal metabolism) through a single and simple measure. We have also cited before the example of thermoregulatory behaviour of early weaned piglets that parallels biological changes (Orgeur *et al.*, 2001).

Behaviour has therefore been used extensively to analyse environmental needs or preferences. Some are quite obvious, as related to the ergonomy of the animal's life, such as the disposition and design of drinking spouts and feeding troughs, the physical characteristics of the ground and the design of alleys to allow convenient displacement of the animals. Preference tests are useful but more difficult to interpret in terms of welfare, and it is necessary to measure the strength of preferences to know whether they can be said to constitute needs that may induce psychological and / or physiological disturbances when they cannot be satisfied. All these behavioural studies are important to design an optimal environment for the animals (Jensen *et al.*, 2005).

Behaviour is also a classical symptom to the diagnosis of health problems, like the general behavioural depression accompanying fever (reduction of movements, social interactions and feed intake) and known as sickness behavior (Dantzer and Kelley, 2007), or lameness indicative of locomotor problems and associated pain.

There is a lot more discussion about the significance and interpretation of so-called abnormal behaviours. Those fall into several categories:

a. Reduced behavioural activity/reactivity (apathy), eventually with a reduction of food and water intake is a frequent symptom in animals adapting to a novel environment.
b. Aggressive behaviours are primarily the expression of social behaviour of pigs. Indeed aggressive behaviours are frequent for food competition or when mixing unacquainted animals, such as at the time of weaning or when pigs from different pens are mixed before being loaded to the slaughterhouse or in the lairage area. These aggressive interactions are a frequent source of wounds and exhaustion, eventually leading to death in sensitive animals, like those carrying the stress-susceptibility allele of the ryanodine receptor. They also compromise meat quality, giving meat with a low pH, pale, soft and exsudative (Sellier, 1998; Faucitano and Geverink, in this book). Therefore mixing animals from different social groups should be as limited as possible. Outside these periods, aggressive behaviours usually occur at low frequency when there is no competition, such as for food for instance, and when group size is kept small enough to allow the expression of normal social behaviour. Aggressive interactions have been shown to increase in situations where the welfare of the animals is threatened (Beattie *et al.*, 1995, 1996; De Jonge *et al.*, 1996; Haskell *et al.*, 1996). It should also be taken into consideration

that large differences may occur between individuals. Genetic differences are well documented in experimental animals but little has been done in pigs (McBride *et al.*, 1964; Torrey *et al.*, 2001; Rhydmer and Lundeheim, in this book).

c. Many studies have been published about the development of abnormal behaviours in general and more specifically stereotyped behaviours, in particular with reference to various parameters of the environment, with a major influence of feeding (see reviews in Dantzer, 1986; Lawrence and Terlouw, 1993; Mason, 1991; Mason and Latham, 2004). It is generally agreed that the development of stereotyped behaviours is a sign of poor welfare, although there may be large differences in the vulnerability of individual animals to develop abnormal behaviours. An extreme form of abnormal behaviour is cannibalism that is usually directed in pigs towards the tail and ears and sometimes leaving to death (Schroder-Petersen and Simonsen, 2001).

When it comes to the study of general behavioural activity and reactivity – as opposed to the longitudinal study of the response to a given stimulus as usually done in laboratory experiments – it is necessary to disentangle the various factors influencing behavioural reactivity besides, or in interaction with the factor under study. Indeed large individual differences have been described in emotional behavioural reactivity, altogether known as temperament (Cloninger, 1994). It has been shown in laboratory animals, like in humans, that the whole range of variation is contributed to by a limited number of 'factors' like activity, emotionality and aggressiveness (Ramos and Mormède, 1998). This multidimensionality was also described in pigs (Lawrence *et al.*, 1991; Jensen *et al.*, 1995b; Thodberg *et al.*, 1999; Van Erp-van der Kooij *et al.*, 2002) but deserves more work for a comprehensive understanding. A simple test, known as backtest, was designed to characterise individual differences in behavioural reactivity (Hessing *et al.*, 1993). It is based on the propensity of individual animals to display tonic immobility when they are put on their back and lightly restrained. Several studies have shown that individual differences in behavioural reactivity as measured by the backtest have a number of physiological and zootechnical correlates (Hessing *et al.*, 1994, 1995; Schrama *et al.*, 1997; Erhard and Mendl, 1999; Bolhuis *et al.*, 2000; Ruis *et al.*, 2000; Van Erp-van der Kooij *et al.*, 2000; Geverink *et al.*, 2003). Although this test is the matter of discussions about its interpretation and significance (Jensen, 1995; Jensen *et al.*, 1995a), it has a very heuristic value to focus behavioural studies to individual differences that are now studied more comprehensively. As for the variation in neuroendocrine responses, individual differences in behavioural activity/reactivity is the result of complex interactions between the genetic make-up of the individual and environmental influences during development (McBride *et al.*, 1964; Hemsworth *et al.*, 1986, 1990; Hemsworth and Barnett, 1992; Beilharz *et al.*, 1993; Désautés *et al.*, 1997; Ramos and Mormède, 1998).

In conclusion, most behavioural changes have no simple relationship with stress and welfare, and must be interpreted in the context of their specific role in homeostatic mechanisms (including their psychophysiological dimension) and of individual variation.

4. Production and pathology

4.1. Production and welfare

The relationship between production level and welfare is far from simple and unidirectional. As the resource allocation theory puts it, all the energy used for adaptation purposes is no longer available for production that should therefore decrease (Beilharz *et al.*, 1993). Indeed, corticosteroid hormones and catecholamines are catabolic and the activation of these neuroendocrine systems is therefore antagonistic to anabolic processes involved in production. Glucocorticoid hormones reduce the activity of sex neuroendocrine systems and therefore reduce the efficiency of reproduction (Wan *et al.*, 1994). Behavioural adjustments are also energy consuming (Schütz *et al.*, 2002).

There is no doubt that health problems, recurrent pain due to skin lesions or wounds, adverse environmental conditions like excessive density, bad air quality, usually reduce weight gain and overall productivity. However, the reverse is not true that a maximal production rate necessarily reflects optimum welfare. Practices to improve production via genetic selection or the use of growth promoters have been questioned since they may have a negative impact on welfare or mask the negative effect or bad welfare on production performances. On the other hand, resources used for adaptation purposes, and therefore unavailable for production, may eventually be used in processes improving welfare. Although most studies aimed at removing negative inputs, less work has been done on positive emotions that may activate adaptation systems and consume energy as well. For instance, I have cited earlier experimental data showing that the HPA axis may be activated in an enriched environment (de Groot *et al.*, 2000; De Jong *et al.*, 1998, 2000). However, experiments comparing husbandry methods for growing-finishing pigs show that enriching the environment can also increase production. Pigs raised on bedding and eventually with free access to an outdoor area are more active, eat more and grow faster than controls raised in a conventional system with a totally slatted floor, the differences in meat quality being at most modest, although a wide range of variation can be found in the literature (Van der Wal *et al.*, 1993; Lyons *et al.*, 1995; Nicks *et al.*, 1996; Sather *et al.*, 1997; Geverink *et al.*, 1999; Beattie *et al.*, 2000; Klont *et al.*, 2001; Lebret *et al.*, 2002, 2004, 2006).

Finally, it should be kept in mind that production is usually monitored at the level of the group, when welfare is an individual experience, so that a good overall performance of a production unit should not preclude attention given to individual animals.

4.2. Pathology and welfare

Good health is the first prerequisite for a sound production system ensuring animal welfare together with efficient production. The question here is whether pathology can be used as an index of the impact of the environment on the animal, and therefore as a measure of welfare.

The immune system is a major player in the defense of the organism against pathogens, and is also sensitive to stress factors. Indeed cortisol is a powerful anti-inflammatory hormone and can influence a number of immune mechanisms. This led to the general concept of stress-induced immunosuppression that is an over-simplification of the complex bi-directional relationships between stress responses and the immune system (Dantzer and Mormède, 1995; McEwen *et al.*, 1997; Dantzer, 2004). Just to cite two examples among thousands, we showed in rats that the consequences of repeated defeat in social encounters on immune functions were different according to the social status of the animals (Raab *et al.*, 1986). In another experiment, chronic social stress induced by daily reallocation of animals in different social groups, and that provokes an intense activation of the HPA axis and/or the ANS, did not change the indices we used to monitor immune system activity (Klein *et al.*, 1992). Although various parameters related to immune functions are being monitored in welfare-related studies, their interpretation in terms of stress and welfare is far from obvious (see for instance Hicks *et al.*, 1998; de Groot *et al.*, 2000; Tuchscherer *et al.*, 2002).

Besides major epizootic diseases determined by specific pathogens and highly contagious, enzootic diseases, like respiratory, digestive and reproduction disorders, are characterised by a low mortality, high morbidity with variable expression of the disease, frequently associated with bad zootechnical and economical performances, and by a complex, multifactorial determinism in which pathogens do not play the main role. Ecopathological approaches have been used to disentangle the various factors involved in the etiology of these 'production diseases'. They consider numerous factors related to stockmanship, genetics and general health of the animals, herd management, characteristics of the environment, feed composition, distribution and intake, technical performance of the farm and relate these factors to the occurrence of disease with multi-dimensional statistical analyses (Madec and Tillon, 1988). For instance in a study of digestive disorders at weaning, factors like the number of piglets per pen, the number of litters of origin per pen, the feeder length available per pig, the stocking density were shown to be risk factors to the occurrence of the disease (Madec *et al.*, 1998). These various characteristics of the environment are obviously relevant to animal welfare as well, so that these production diseases may be an important integrative indicator of the quality of the environment. Furthermore, this approach has the advantage of being multidimensional, eventually exhaustive, and without any prevailing hypothesis about the causal factor(s) and the intermediate mechanisms leading to disease. It would be worthwhile extending this methodology to other parameters characterising animal welfare, like neuroendocrine profile or behavioural traits.

5. Conclusion and perspectives

The first principle to agree upon is that welfare is to be assessed at the level of the animals, and eventually at the level of the individual animal since it is a personal subjective experience. Designing an optimal environment is a sound approach but is not sufficient to ensure welfare. At the level of the organism adaptation is a complex, multifaceted process in which individual psychobiological characteristics – that result from the interaction of genetic and developmental factors – shape the perception of the environment and coping responses. This process takes place in the context of homeostasis. Since we are not yet able to reach directly the cognitive and emotional state of the pig, we have to rely upon the expression of its psychological state in biological functioning, behavioural expression, production efficiency and eventually pathological outcomes. However, most of the criteria available are not specific to stress and welfare problems, since they are sensitive to many influences related to their role in homeostatic processes, or, in the case of pathology, to the action of specific pathogens. It is therefore critical to confront different approaches for a comprehensive assessment of welfare (Figure 6).

In short term studies, a wide range of measures are available. Probably the most difficult problem here is the interpretation of the data in terms of welfare. At least, we have now enough evidence to avoid conceptual oversimplifications like equating an increase of circulating cortisol levels with stress, or biological stress responses with bad welfare. Taking into account the multivariate nature of the response to environmental challenges helps interpreting the results, such as using several biological indices instead of cortisol levels alone, or confronting biological and behavioural responses. Another open question is the extent of individual vulnerability. It is now well documented that behavioural reactivity in animals and mood disorders in humans, as well as biological stress responses are largely dependent upon genetic and developmental factors and more studies should be done in pigs to explore these processes and understand the mechanisms of individual variability of psychobiological reactions to environmental factors.

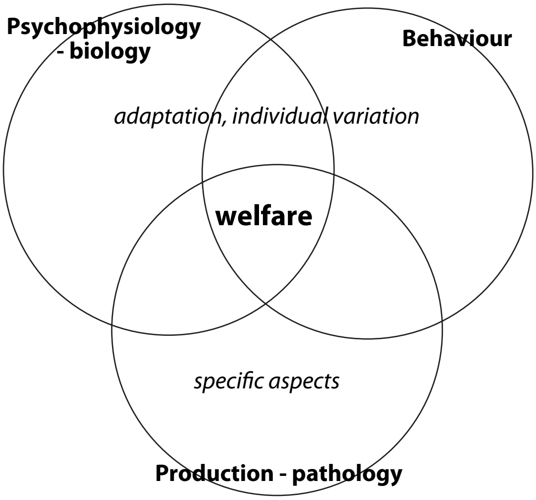

Figure 6. Multidimensional approach of welfare. Assessment of welfare relies upon the different approaches used to study pathophysiology of adaptation, such as psychophysiological biology, behaviour, and their consequences on production traits and pathology. However, none of these measures is uniquely related to welfare, since they are also influenced by many other factors such as the involvement of these processes in the maintenance of homeostasis, the individual variability or the intervention of specific pathogens for instance. Therefore a comprehensive knowledge of animal welfare can come only from the confrontation of the results obtained with these various approaches.

In chronic studies, the experimental approach is still useful. Indeed, as compared to acute stress responses, allostatic adjustments of physiological systems of animals subjected to sustained stress has not been explored thoroughly. On the other hand, as stressed by Rushen (2003), the epidemiological approach is underutilised. Indeed experimental approaches of system-to-system comparison do not take into account the huge diversity characterising the animals' environment. The examples of ecopathological studies presented earlier clearly show that individual environmental factors can be found to influence pathological outcomes. This approach is however a formidable challenge if we were to monitor a wide range of parameters from the animals, to be related to a description of the environment as exhaustive as possible, including its social, physical and human components (Bracke *et al.*, 2002a,b). Nevertheless, it appears to be unique to take into account the multiplicity of the factors contributing to animal welfare. In these studies still more than in acute studies, it will be important to take into account individual variability that deserves a more sustained interest.

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Chapter 3. The welfare of pregnant and lactating sows

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Abstract

This chapter reviews the many aspects of pregnant and lactating sow welfare. The first issue addressed is hunger and thirst, brought about by food and water restriction. The impact of food restriction on the persistence of feeding motivation and stereotypic behaviour development, as well as the use of high fibre diets as an alternative to concentrate feeding are discussed. Food restriction also causes competition at feeding when sows are housed in groups, but various management techniques may be used to reduce the negative effects of competition. The second welfare issue is discomfort, which relates principally to the type of housing and flooring, and to the thermal environment. The beneficial effects of providing sows with more freedom of movement are discussed. The third section deals with pain and injuries and explores the various factors affecting the health of animals, in particular, those causing locomotion disorders, skin lesions and vulva biting. The impact of nose ringing on welfare is also discussed. Pregnant and lactating sows have behavioural needs, such as exploration and foraging, locomotion, nest building and social contacts. The various ways to satisfy those needs are addressed in the fourth section of the chapter. Finally, the potential impact on fear, stress and suffering, of various social and environmental factors, including housing, are discussed in the last section.

Keywords: sow, welfare, hunger, discomfort, pain, behavioural needs, stress

1. Introduction

The pregnant and lactating sows' environment has changed considerably over the past 50 years. A better control of environmental factors, such as feeding and hygiene, along with genetic selection, have led to a remarkable increase in reproductive performance and production efficiency. However, as pig production intensified, many concerns with regards to sow welfare have been raised by the public and the scientific community. This chapter reviews the many aspects of pregnant and lactating sow welfare, by addressing each issue identified by the Farm Animal Welfare Council of the United Kingdom's five freedoms (FAWC, 1992): hunger and thirst, discomfort, pain and injuries, behavioural needs, and fear, stress and suffering.

2. Hunger and thirst

2.1. Food restriction

Breeding sows are commonly fed to maintain a relatively constant body condition throughout the reproductive cycle for good health and optimal performance (Dourmad *et al.*, 1994, 1996). This involves a restriction of feed intake during gestation to prevent excessive body weight gain and fat deposition, as these cause farrowing and locomotion problems and subsequently lower reproductive performance. Pregnant sows typically receive their whole daily feed in one or two small, concentrated meals that are rapidly consumed. The usual restricted feeding level, whilst adequate to meet nutrient needs of sows and maximise economic performance, might not fulfil sows' appetite and their need to express feeding behaviours (Rushen *et al.*, 1993). Indeed, the level of feed provided corresponds to about 0.40 to 0.60 of the voluntary intake (Petherick and Blackshaw, 1989; Brouns *et al.*, 1995), which results in a low level of satiety and a reduced performance of appetitive and consummatory sequences of the feeding behaviour. A low feeding level has been linked to the occurrence of stereotyped activities, which are described as behavioural patterns performed repetitively in fixed order and with no apparent function. These behaviours are more prevalent in the immediate post-feeding period, and have been attributed to the limited nutrient supply in combination with the reduced access to a foraging substrate in stalled or group-housed sows (Rushen, 1984, 1985; Appleby and Lawrence, 1987; Terlouw *et al.*, 1991; Lawrence and Terlouw, 1993; Spoolder *et al.*, 1995). The occurrence of stereotyped behaviour has been considered to reflect heightened feeding motivation after feeding and interpreted as an indication of impaired welfare (Wiepkema *et al.*, 1983).

Under increasing public pressure and reinforced implementation of European legislation on welfare, doubts have emerged on the welfare status of pigs in intensive production systems. The inability of pregnant sows to express spontaneous feeding motivation fails to satisfy one of the five basic requirements of welfare status considered in legislation: freedom to express normal behaviour (Council Directive 91/630/EEC, 1991). Nevertheless, the high intake capacity of pregnant sows limits any attempt at offering a conventional diet *ad libitum* because of concomitant obesity and detrimental effects at farrowing and during lactation. An alternative way of satisfying feeding motivation whilst maintaining sows on restricted energy supply, is to provide diets with additional roughage. Fibrous materials can be provided in a rack or on the floor, or by including high levels of fibrous ingredients in the diet, allowing increased feed bulk without increasing the energy and nutrient allowances. Incorporation of fibre in diets to increase bulk, without changing the daily dietary energy supply, has been shown to result in at least a doubling of eating time, a 20% reduction in feeding rate, a 30% reduction in operant response in feed motivation tests, a reduction of 7-50% in stereotypic behaviour, and a decrease in general restlessness and aggression (Meunier-Salaün *et al.*, 2001, 2002). Results suggest a reduced feeding motivation, but only if nutrient intake with fibrous diets meets the nutrient requirements of the animals. Investigations of circulating glucose, insulin and volatile fatty acid levels in sows fed fibrous diets indicate a more constant nutrient absorption and greater microbial fermentation in the gut, which should increase satiety (Rushen *et al.*, 1999; Ramonet *et al.*, 2000).

Some countries such as the Netherlands have imposed a minimum level of inclusion of crude fibre in pregnant sow's diet in order to reduce hunger and promote welfare. Moreover, the new directive 2001/88 of the European Council imposes to give a sufficient quantity of bulky or high-fibre food as well as a high-energy food (Council Directive 2001/88/EC). A permanent access of sows to foraging substrates such as hay or straw is also required.

Restricted feeding supply also leads to feeding competition in group-fed sows. In addition to injuries and stress imposed on sows, this competition in feeding situations results in unequal intake between sows within the group, which has detrimental effects on body reserves, especially for the low-ranking animals (Csermely and Wood-Gush, 1986; Edwards, 1993; Brouns and Edwards, 1994; Signoret *et al.*, 1995). This is one of the major reasons why sows are usually housed in stalls during gestation. However, keeping gestating sows in stalls may not be the best system for their welfare (see sections on Discomfort and on Pain and Injuries). In order to promote the use of group housing systems, we need to find ways to feed the animals that will reduce competition and insure adequate and uniform body condition throughout the reproductive cycle (Figure 1). Low-density diets could be one solution. Indeed, a European report showed that feeding a high-fibre sugar beet pulp diet *ad libitum* to group-housed sows allows low-ranking sows to achieve feed intake and gestation gain comparable with that of high-ranking sows (Brouns and Edwards, 1994).

The competition at feeding can also be reduced by increasing individual space allowance (Weng *et al.*, 1998), improving feeding design and procedures, modifying group size, and maintaining social stability within a group (Barnett *et al.*, 1987b, 2001). In small groups (< 20), feeding in individual stalls rather than on the floor has been shown to reduce the frequency of injuries caused by fights (Barnett *et al.*, 1992; Edwards *et al.*, 1993). In large groups (> 100), the use of an electronic feeding system (EFS) protects the animals engaged in feeding activity. However, there is a risk of body lesions linked to feeding competition in animals waiting at the entry of

Figure 1. Feeding stalls (Photo courtesy of M.C. Meunier-Salaün, INRA).

the feeding area (Van Putten and Van de Burgwal, 1990a), especially for subordinate animals who wait longer before getting access to the feed (Hunter *et al.*, 1988). The start of the feeding cycle during the night period has been proposed as a way to reduce the competition level (Hodgkiss *et al.*, 1998; Jensen *et al.*, 2000). Enrichment of the pen with chewing material such as straw can also attenuate the social competition due to feed restriction (Spoolder *et al.*, 1993; Durrell *et al.*, 1997; Jensen *et al.*, 2000), but the effects depend on the nature of substrate and on the method of enrichment. For instance, the frequency of aggression-related injuries recorded in a group of 30 sows was higher when straw was supplied as bedding rather than in a rack (Jensen *et al.*, 2000).

2.2. Water restriction

Gestating sows generally receive water *ad libitum*, either from a nipple or in the feed trough. However, some producers may distribute water only during specific periods of the day, in order to avoid excessive consumption (more than 12 litres per day). Indeed, in pregnant sows, feed restriction induces excessive water intake. This abnormal drinking behaviour has been associated with persistent feeding motivation because of hunger (Rushen, 1984) and to some degree of frustration or stress (Fraser *et al.*, 1990). However, there is no evidence that this activity serves no function; excessive water intake may serve to distend the stomach (Robert *et al.*, 1993). Rather than being regulated by thirst, excessive drinking would therefore be aimed at reducing hunger in pregnant sows. Considering this, as well as the risk of thirst and dehydration in hot weather conditions, we can say that water restriction is detrimental to welfare.

3. Discomfort

3.1. Housing

One of the most important determinants of sow comfort is housing. Although gestation stalls facilitate the control of feed intake and aggression, they have been criticised because they restrict freedom of movement. Furthermore, the new directive 2001/88 of the European Council (Council Directive 2001/88/EC) requires that sows are kept in groups, from four weeks after breeding until one week before the expected time of farrowing.

According to the Farm Animal Welfare Council of the United Kingdom (FAWC, 1992), sows should be able to stand up, lie down and turn around comfortably. Research has shown that sows in stalls have difficulty getting up quickly and lying down (Marchant and Broom, 1996b). The increased time spent lying down and the frequent postural changes while lying observed in stalled sows, compared to loose-housed sows, may reflect a greater difficulty to get up (Taylor *et al.*, 1988). Comfort may be improved by increasing stall size. Indeed, Curtis *et al.* (1989a) reported that a 250 kg sow requires at least 220 cm long x 86.4 cm wide x 99 cm high, while many stalls used in production are too narrow (61 cm). More recently, McGlone *et al.* (2004) measured the physical dimensions of sows in a commercial situation and concluded that the majority of sows would be contained, while lying down, in a stall measuring at least 72 cm wide, and suggested that most commercial gestation stalls are not wide enough for comfort. Providing sows with more freedom of movement may not only improve comfort but may also have beneficial effects on their physical and mental health (see sections on health and behavioural needs). In addition, group housing of pregnant sows allows them a better control of their environment, which should result in improved comfort. It is then possible to provide animals with some environmental variation such as a wallow or a misting area, bedding or foraging substrate, areas of high and low air movement and of variable lighting intensity, giving the sows even more opportunities to control their comfort (Gonyou, 2003).

A good housing system in the farrowing room should not only accommodate the needs of the sow, but should also provide comfort, warmth and protection for the piglets. While the farrowing crate has the potential to reduce piglet mortality (McGlone and Curtis, 1985; Curtis *et al.*, 1989b; den Hartog *et al.*, 1993; Blackshaw *et al.*, 1994; Cronin *et al.*, 1996), it reduces the sow's freedom of movement and ability to perform nesting behaviour (see section on Behavioural needs). Some studies reported a higher plasma cortisol in sows housed in crates compared to loose housed sows before (Jarvis *et al.*, 2001) and after (Cronin *et al.*, 1991) parturition. Furthermore, preference tests showed that sows prefer a cage that allows them to turn around freely (Phillips *et al.*, 1992b). Phillips *et al.* (2000) stated that the general use of farrowing crate and the lack of bedding restrict the ability of sows to select a suitable micro-climate for themselves and their litters (Figure 2). Even though sows spend considerably less time in the farrowing crate than in the gestation stall, it would be worth looking at alternative systems that provide greater freedom of movement, while offering protection and warmth to the piglets (for a review, see Arey, 1997).

3.2. Flooring

The type of flooring used in the sow environment may affect hygiene, injuries to legs and feet, and performance (Kornegay and Lindemann, 1984). Flooring should be non

Figure 2. Nursing piglets (Photo courtesy of J. Chevalier, INRA).

slippery to allow the sow a better control of the speed of her descent when lying down. It should also provide a well-insulated, clean, comfortable and non-slippery surface for the piglets (Svendsen *et al.*, 1986). While metal products offer good hygiene and ease of cleaning, evidence suggests that other floor types may be more suitable for sow comfort. For instance, concrete floor offers a better foothold than perforated metal slats (Christison and De Gooijer, 1986), and solid concrete floors result in less injuries to the sow's teats and legs than perforated floors (Edwards and Lighfoot, 1986). Preference tests have shown that, given the choice between concrete, plastic-coated rod and galvanised metal rod, farrowing sows avoid metal floor during and immediately after farrowing, and overall, prefer concrete floor (Phillips *et al.*, 1996). On the other hand, several problems such as an increase in legs and teats abrasion in piglets, lower thermal comfort and cleanliness have been reported for concrete floors (Phillips *et al.*, 1992a). Covering a concrete floor with epoxy-paint and added quartz sand has been shown to be too slippery for the sow, and while sows are more comfortable on rubber mats, piglets have larger and deeper knee wounds (Gravas, 1979). The choice of the floor will be a compromise between sow and piglet welfare. As Phillips *et al.* (1996) pointed out, the best flooring would be a concrete slab directly underneath the sow, with a less abrasive surface to either side for the piglets.

3.3. Thermal environment

Minimum and maximum temperatures that limit the thermal comfort zone, also called critical temperatures, will vary according to several factors, such as the age, breed, floor type, air speed, group size, energy intake, productivity level, relative humidity, degree of skin or floor wetness, and degree of acclimatisation of the animal (Curtis, 1983; Charles, 1994). The temperatures reported in the literature should only be used as indications. For instance, the lower critical temperature for individually housed pregnant sows has been reported to be between 20 and 23 °C (Noblet *et al.*, 1989). Lactating sows produce more heat than pregnant sows and according to Black *et al.* (1993), the lower and upper limits of their thermal comfort zone would be 12 and 20 °C, respectively. Sows may be kept in colder environment, but feed intake must be increased to compensate for the increased heat production. At 30 °C, sows show evidence of heat stress, such as reduced feed intake and increased weight loss compared to sows kept at 18 or 25 °C (Stansbury *et al.*, 1987). Thermal requirements of sows are in conflict with those of piglets. Indeed, newborn piglets have a lower critical temperature of 34 °C. Interestingly, when given the choice, sows preferred a 35 °C floor than a 29 or a 22 °C floor (room temperature of 24 °C), from the time of farrowing to day three after farrowing. The preference was reversed by the time piglets were seven days of age (Phillips *et al.*, 2000).

4. Pain and injuries

The health of gestating and lactating sows can be affected by different environmental factors such as exposure to infectious diseases, group size, floor type, space allowance, social structure within group (stable or dynamic), pen shape, lack of bedding, feed or water schedule and delivery system, climatic factors (ventilation, temperature), waste system, stockmanship and a host of other factors. While various housing systems are used for gestating sows (individual/group), the crate is the dominant one for the farrowing- lactating sows in European countries and North America. From a welfare point of view, health problems have been associated mainly with the lack of freedom, the environmental design and the social dynamic within groups. The main concerns are locomotion disorders, skin lesions, vulva biting and discomfort associated with the use of nose rings for sows raised outdoors.

4.1. Locomotion disorders

The degree of exercise or movement performed by the sow interacts with the quality of flooring to influence foot health, leg weakness and lameness. Jensen *et al.* (1995) reported a higher level of integument lesions in late pregnancy when sows were raised in stalls compared to group-housing, suggesting a long-term pressure against hard surfaces (callositas/alopecia in legs and leg swelling). On the other hand, gestating sows raised in groups show a higher frequency of lesions at the claw than females penned individually (Kroneman *et al.*, 1993). In addition, Backus *et al.* (1997) found that sows fed with an electronic feeding system (EFS) or a trickle-feeding system experienced significantly more locomotion disorders than did sows housed in stalls or free access stalls.

The impact of quality of flooring on feet injury and lameness has been reviewed by Von Borell *et al.* (1997). In group housed sows, the supply of a bedding substrate such as straw has been shown to reduce the frequency of abnormal gait, compared to sows raised on a slatted floor (Andersen *et al.*, 1999). Regarding slatted floors used in sows housing, the critical factors for foot health are the inadequate spacing between slats and the roughness of the surface. On the other hand, hoof overgrowth leading to lameness has been reported on smooth surfaces or deep litter systems (Geyer, 1979). Therefore, it appears necessary to allow some abrasion without excessive damage to the feet. In a survey of 15 herds, Gjein and Larssen (1995) reported an increased risk of lameness associated with concrete vs. plastic slats and with poor floor hygiene.

Exercise leads to higher muscle mass and bone strength (Marchant and Broom, 1996a), and improves cardiac function (Marchant *et al.*, 1997). It reinforces also the immune system (Golub and Gershwin, 1985), and reduces parturition length (Ferket and Hacker, 1985), which in turns may promote piglet survival. Exercise during gestation through loose housing system has been associated with a reduced incidence of lameness in gilts (Hale *et al.*, 1984). During lactation, locomotion problems have been reported to be a major cause of death or culling (Mc Kee and Dumelow, 1995; Barnett *et al.*, 2001).

4.2. Skin lesions

Skin lesions can be the result of aggressive interactions following grouping or feeding competition within groups of gestating sows. They can also be associated with an inadequate pen or stall environment (flooring, stall design) during gestation or lactation.

A great deal of research has been done on housing conditions during gestation. A greater injury rate has been classically reported among group-housed gestating sows compared to those individually penned (Barnett *et al.*, 2001). Decubital ulcers on the shoulders are the main lesions in individually housed sows, while feeding-related aggression is the major cause of body lesions in group-housed sows. Thus, Gonyou *et al.* (1990) reported more frequent and severe injuries on the ear, neck, throat, shoulder and sides in gilts housed in an ESF system than in those housed in stalls, while gilts penned in stalls exhibited more frequent abrasions (calluses and dehairing) on the rump and the tail due to contact with the stall. In the first case, the ESF identification collar caused most of the neck wounds. The lack of additional roughage has been shown to increase the risk (1.7 times) of body lesions in group-housed sows (Gjein and Larssen, 1995). In stalls, the provision of extra space increases the ease of movement for getting up and lying down (Marchant and Broom, 1996b; Anil *et al.*, 2002), thus reducing the risk of injuries.

The incidence of body lesions inflicted to gestating sows at mixing can be affected by the experience of the females. Indeed, Van Putten and Buré (1997) recorded a decreased number of lesions at the time of introduction in a dynamic group with gilts that had been mixed three to four times before five months of age, compared to less experienced animals (two or no mixing). In addition, when introduced in a dynamic group, the new gilts showed more body injuries than the older sows, due to their greater implication in agonistic interactions and to higher aggression from the older females (Dingemans *et al.*, 1993; Spoolder *et al.*, 1997). To limit the effect of aggression on injuries within a dynamic group, it is preferable to mix sows immediately after weaning or at least 29 days after mating (Burtfoot *et al.*, 1997). The use of masking odours and 'mood-altering' drugs has been shown to postpone aggression rather than to reduce it, and in some case, to result in prolonged social instability (Mc Glone *et al.*, 1981; Mc Glone, 1985; Luescher *et al.*, 1990).

There is little evidence for an optimum group size that would limit the intensity of fights at mixing. However, the impact of fights at mixing tends to be reduced in groups that are stable over successive gestations (Simmins, 1993; Burtfoot *et al.*, 1994; Broom *et al.*, 1995) and in groups of limited size (Taylor *et al.*, 1997). Independently of group size, an increased space allowance per animal has been shown to promote avoidance behaviours and thus to reduce body lesions (Mujuni *et al.*, 1986; Edwards *et al.*, 1993; Olsson *et al.*, 1994; Weng *et al.*, 1998). Within large groups of sows (> 100), the existence of sub-groups using distinct sections of the space plays in favour of social stability (Van Putten and Van de Burgwal, 1990b; Moore *et al.*, 1993). Forming sub-groups of sows prior to their introduction into the larger group may also help reduce aggression (Durrell *et al.*, 2003). More than the space allowance per animal, the design of the pen can affect the intensity of aggressive interactions in groups of gestating sows and consequently the incidence of body lesions (Barnett *et al.*, 1992). At mixing, the provision of protection through partitions or stalls can confer welfare benefit by providing escape area for subordinates, and by reducing the frequency of aggressive interactions between sows (Barnett *et al.*, 1992). However, the access to individual stalls supplied with food can increase the risk of bites directed to the ano-genital area (Petherick and Blackshaw, 1987). Pen divisions have also been reported to potentially reduce the number of injuries to sows at mixing but their efficiency depends on the type of partitions (Luescher *et al.*, 1990; Van Putten and Van de Burgwal, 1990b; Edwards *et al.*, 1993). Finally, the feeding level supplied at mixing has few effects on the aggressive interactions within groups and consequently on the injury level (Luescher *et al.*, 1990; Edwards *et al.*, 1994).

After the establishment of a hierarchy within groups of gestating sows, the injury level mainly depends on the feeding competition related to food restriction or the difficulty for individual sows to access the trough (Csermely and Wood-Gush, 1987; Edwards, 1992). The factors affecting the occurrence of skin lesions due to high aggressive level during feeding periods are very similar to those related to mixing. The competition at feeding can be reduced by increasing individual space allowance (Weng *et al.*, 1998), by improving feeding design and procedures, by modifying group size, and by maintaining social stability within a group (Barnett *et al.*, 1987b, 2001; see section 2 in this chapter).

Injuries incurred during lactation have been associated with the type of flooring in the farrowing crate, which determines the comfort level of the sow when she stands or lies down. Inadequate slip resistance, traction or void width may alter sow's body position during postural changes and thus induce skin lesions and teat damage (Barnett *et al.*, 2001). Difficulties in lying down behaviour in lactating sows have been related to feet lesions and overgrown hooves (Bonde *et al.*, 2004). Experience of loose housing during gestation has been shown to improve the ability of sows to change their posture in the farrowing crate, and thus, to be beneficial for skin health on the first days post-partum (Boyle *et al.*, 2002). The effect was stronger when gestating sows had been penned on a bedded floor (Boyle *et al.*, 2000).

4.3. Vulva biting

Vulva biting is a major welfare problem in gestating sows, especially with some group housing systems (Gjein and Larssen, 1995; Rizvi *et al.*, 1998). A high risk of vulva injuries associated with feeding access or aggressive interactions within group has been reported in numerous studies (Edwards and Riley, 1986; Van Putten and Van de Burgwal, 1990a; Vieuille-Thomas *et al.*, 1995; Rizvi *et al.*, 1998). The incidence is higher in herds with EFS compared to other group housing configurations (Olsson *et al.*, 1992), because in this system, sows stand in line for long periods of time during which they have no way to protect themselves (Edwards and Riley, 1986). Indeed, all lesions are due to biting performed by pen mates waiting in line at the entry of the feeder. Finally, the relative risk of vulva lesions is reported to be 2.6 times higher in group-housed sows without roughage, compared to those receiving roughage (Gjein and Larssen, 1995).

4.4. Nose rings

In order to limit pasture damage done by gestating sows raised outdoors, it is common practice to place metal rings in their nose to reduce their amount of foraging. This practice has been associated with discomfort when the animals root, and is consequently detrimental for their welfare. Nasal ringing has also been reported to affect other oral activities such as grazing and stone chewing, which may also have welfare implications (Horrell *et al.*, 2000, 2001). As the rooting motivation has been suggested to be independent of hunger (Horrell *et al.*, 1997), it has been proposed to provide rooting material instead of using nose rings, in order to reduce the pasture damage. However the supply of roughage in the form of sugar-beet pulp has been unsuccessful (Braud *et al.*, 1998) and the provision of high bulk feed such as Swedes (*Brassica napus* L. var. napobrassica) had limited success (Edge *et al.*, 2005). Thus, further research is required on the welfare implication of nose ringing.

5. Behavioural needs

The concept of behavioural (or ethological) 'need' refers to particular behaviours for which the animal is highly motivated. It has been suggested that behaviours that are primarily controlled by internal factors (neural, hormonal) are more likely to fall into the behavioural need category (Hughes and Duncan, 1981; Dawkins, 1983). It is assumed that when the physical environment prevents an animal from performing such behaviours, suffering and reduced welfare may result (Dellmeier, 1989). For some behaviours, motivation is so strong that animals will perform a 'vacuum activity' when an appropriate substrate is not available (Vestergaard, 1980). However, as Dawkins (1990) pointed out, it is difficult to interpret these 'vacuum activities' as signs of suffering, since their performance may itself reduce motivation.

The concept of behavioural needs underlies one of the five freedoms of the Farm Animal Welfare Council of the United Kingdom (FAWC, 1992): 'freedom to express normal behaviour by providing sufficient space, proper facilities, and company of the animal's own kind'. In sows, environmental factors such as close confinement, lack of bedding and food restriction prevent the performance of behaviours that may be important to sow's welfare.

5.1. Exploration and foraging

Exploratory behaviour may be divided into two categories: extrinsic and intrinsic. Extrinsic exploration is the appetitive component of other motivational systems (e.g. feeding motivation) whereas intrinsic exploration serves to familiarise the animal with its environment and to gather information. Intrinsic exploration can be further divided into inspective (in response to an environmental change) and inquisitive (to initiate an environmental change) exploration (Berlyne, 1960). In growing pigs, the exploration of a novel environment has been considered as a form of inquisitive exploration (Wood-Gush *et al.*, 1990).

According to Wood-Gush *et al.* (1990), exploratory behaviour is an important consideration with regard to animal welfare, since intensive husbandry systems offer an extremely monotonous environment. When kept in a semi-natural environment, pigs devote an appreciable proportion of their time 'moving between parts of the enclosure, examining their distant and immediate environment, collecting, carrying and manipulating food items' (Stolba and Wood-Gush, 1989). Free-range lactating sows spend more than 50% of their day time rooting, grazing and licking feed (Jensen, 1988). In growing pigs, a barren environment increases abnormal behaviour by redirection of exploratory behaviour towards pen mates (Wood-Gush and Vestergaard, 1993). On the other hand, the presence of straw in the pen allows the expression of a strong exploratory motivation (Fraser *et al.*, 1991). Some evidence showed that nutritional needs (e.g. protein) in ad libitum fed pigs can increase the amount of time rooting straw (Jensen *et al.*, 1993), and therefore rooting straw is not solely a form of intrinsic exploration but may serve to satisfy a foraging motivation.

Very few experiments addressed the issue of intrinsic exploration in sows, and results from experiments on growing pigs may not be directly applicable to sows, because of age differences. However, a great deal of research has been done on foraging behaviour in food-restricted sows (see section on Hunger and Thirst), which could be considered as a form of extrinsic exploration because of the underlying feeding motivation. When straw is offered to food restricted sows, they spend a considerable amount of time performing foraging behaviour such as nosing and rooting (Spoolder *et al.*, 1995). The use of a foraging device ('Edinburgh Foodball') designed to deliver small food rewards randomly when rooted by the animal, showed that Foodball activity (push and feed) is primarily motivated by food (Young *et al.*, 1994). Indeed, when the Foodball does not offer any supplemental food, the sow redirects her rooting behaviour on the straw. When no Foodball is present but a higher level of food is offered, sows still root on straw, but at a lower level, which is similar to the level observed in the presence of the Foodball. Whether rooting on straw when food level is high may also be explained by intrinsic motivation to explore remains unclear. More research is needed to determine to what extent sows have a motivation to explore that is unrelated to feeding motivation. For instance, close confinement prevents investigation of the environment and visual inspection of the area behind the animal (Gonyou, 1996), and these exploratory behaviours may be important to the animal.

5.2. Locomotion

Chronic close confinement appears to increase the motivation for locomotion and kinesis (Dellmeier, 1989). In sows kept in crates, studies have shown that although hunger seems to be the primary cause of abnormal stereotypic behaviours, confinement in stall facilitates their development. Indeed, gestating sows kept in stalls are more prone to stereotypies than sows kept in pens (Vieuille-Thomas *et al.*, 1995). Providing the animals with enough space to explore and exercise may not only satisfy their drive to explore, but also give them the chance to exercise, which is good for their health (see section 4 in this chapter).

5.3. Nest building

During the day prior to parturition, free-ranging feral and domestic sows are highly active. They walk long distance to choose a suitable site isolated from their group and build an elaborate nest (Graves, 1984; Jensen, 1986, 1989; Jensen *et al.*, 1987). Similar patterns of nest building behaviour are shown by domestic sows kept in pens and provided with material (Widowski and Curtis, 1990; Lawrence *et al.*, 1994). They are strongly motivated to walk and gain access to straw or other bedding (Hutson and Haskell, 1990; Haskell and Hutson, 1994, 1996; Haskell *et al.*, 1997). The strong motivation to build a nest in pre-parturient sows appears to be regulated by both internal and external factors (Hutson and Haskell, 1990; Arey *et al.*, 1992). The performance of the behaviour itself seems to be important since sows will engage in nest-building behaviour even when presented with a pre-constructed nest (Arey *et al.*, 1991).

Without any bedding material, sows obviously cannot build a nest, but they will go through the preparative phase of the behaviour 'in vacuum' if kept loose in a pen (Jensen, 1993). Sows in farrowing crates are unable to express their strong motivation to perform locomotion, and may suffer some sort of distress (Haskell *et al.*, 1997). However, they will attempt to build a nest by performing behavioural patterns such as pawing, rooting and nosing at the floor and stall bars, but to a lesser extent than in a less intensive environment (Cronin *et al.*, 1994). This has led to concern about the welfare of sows confined in crates without straw or other building material (Arey, 1997). Indeed, some authors suggested that farrowing accommodation should enable sows to perform nest building in order to reduce their motivation (Arey *et al.*, 1991). Some alternative farrowing systems, such as the Schmidt pen, promote nest-building behaviour and reduce oral/nasal stereotypies (Damm *et al.*, 2003). Environmental enrichment, by providing material, promotes nesting behaviour (Cronin and Amerongen, 1991; Jensen, 1993; Cronin *et al.*, 1994; Thodberg *et al.*, 1999) and would satisfy any need the sow may have to manipulate substrate (Widowski and Curtis, 1990). It can also facilitate parturition (Cronin *et al.*, 1993), which may in turn favour piglet survival. Furthermore, Herskin *et al.* (1998) showed that providing sows with sand and straw increased their reactivity to piglet distress call.

5.4. Social contacts

In modern pig production systems, there are several sources of social deprivation, such as individual housing, early weaning and fostering. Individual housing has been used for many years because it reduces sows' aggression and competition and can help to reduce piglet mortality during the first post-partum days. However, individual housing prevents sows from performing social behaviour as they would do in natural conditions. Indeed, sows naturally live in groups of four to five females and their litter, with an organised social structure (Duncan, 1981).

Individual housing during gestation is still predominant in pig production. Although group housing (Figure 3) is advantageous for sow welfare in many ways, group-housing systems are still under development, as they still face some problems. Indeed, the mixing of unfamiliar gilts or sows usually results in fighting, which leads to the establishment of a social hierarchy (Meese and Ewbank, 1973). Agonistic interactions decrease rapidly over 24h, remain present for a few days during the activity periods (Pritchard *et al.*, 1997) and become scarce after a week, when social stability is well established (Arey, 1999). A high level of aggression within group at mixing and

Figure 3. Group housed sows (Photo courtesy of J. Chevalier, INRA).

thereafter is associated with welfare problems, resulting from injuries and stress responses (see section 4 in this chapter).

In natural conditions, each female isolates herself from the group a few days before farrowing and builds a nest (Jensen, 1986, 1988, 1993). During parturition, newborn piglets reach the teats on their own, using different cues delivered by their mother: heat and odours from the skin, sound through sow vocalisations (Rhode-Parfet and Gonyou, 1991; Horrell and Hodgson, 1992). The mother and its litter leave the nest area at around ten days after farrowing and join the group of females. The mother-young link and the teat order are established a few days after parturition (Gonyou and Stookey, 1987; De Passillé *et al.*, 1988). Fidelity of piglets to their mother is generally observed in group-housed lactating sows (Pedersen *et al.*, 1998). The practice of fostering in intensive husbandry is based on the ability of the sow to adopt foreign piglets but it can lead to welfare problems for piglets if done more than two days after birth (Horrell and Hodgson, 1986; Robert and Martineau, 2001). In return, fostering a new litter by the exchange of all piglets is successful (Orgeur *et al.*, 2000).

Compared to the progressive process of weaning observed between 12 and 17 weeks of life in natural conditions (Newberry and Wood-Gush, 1985; Jensen, 1988, 1989), the early disruption of the mother-young link in intensive conditions has been reported to be a source of social stress, especially for piglets in early weaning conditions (Orgeur *et al.*, 2002). In contrast, an increased freedom as in loose housing or group housing during lactation, tends to reduce the frequency of social contacts and suckling sequences (Stolba *et al.*, 1990; Boe, 1991, 1993; Blackshaw *et al.*, 1994, 1997; Sarignac *et al.*, 1997) and can lead to a spontaneous weaning process (Boe, 1993, 1994), detrimental to the welfare of piglets. Other welfare problems may be encountered in indoor or outdoor group farrowing systems, for instance when a sow chooses to farrow in a pre-constructed nest or hut already occupied by another female (Buré and Houvers, 1989). An alternative system, named family pen, has been proposed to maintain sows with their litter during their reproductive life (Kerr *et al.*, 1988; Wechsler, 1996), thus ensuring the behavioural needs of sows and piglets. However, the high level of piglet mortality during the first post-partum days remains a major disadvantage of such alternative systems. A compromise may therefore be required to achieve a realistic outcome for the welfare of both sows and piglets.

6. Fear, stress and suffering

Sows exhibit fear or stress responses in several occasions during their reproductive life e.g. when moved to an unfamiliar or restricted environment, mixed with unfamiliar sows after weaning or before farrowing or submitted to feeding competition. Difficulties that animals may experience when coping with these stressful events are assessed by biological stress responses (e.g. endocrine, immune, opioid systems) and behavioural disturbances (Broom, 1996). In this section, we will present some housing and social factors causing fear and stress, and the physiological responses of pigs to these challenges. Many other important factors involved in stress responses of animals will be covered elsewhere in this book.

6.1. Housing factors

A number of authors have shown evidence of stress responses in tethered pregnant sows compared with sows housed in individual stalls (crate or pen large enough to turn around) or in group housing systems (Mc Glone *et al.*, 1994; Janssens *et al.*, 1995; Barnett *et al.*, 2001). They demonstrated that tethers induce a sustained increase of basal free cortisol concentrations and an increased responsiveness to ACTH (adrenocorticotropic hormone) and CRF (cortisol releasing factor) challenges. These results were used as a scientific basis for the banning of tethering in the European Union and in Australia. In contrast to these results obtained in tethered sows, stall-housed animals show moderate or no increase in basal free cortisol concentrations and responsiveness to ACTH challenge, compared to pigs housed in groups (Von Borell *et al.*, 1992; Mendl *et al.*, 1993; Jensen *et al.*, 1995, 1996; Pol *et al.*, 2000; Barnett *et al.*, 2001) or turn-around stalls (Bergeron *et al.*, 1996). However, the increase in plasma cortisol when sows are first placed in stalls suggests that it is a stressful event (Becker *et al.*, 1985; Cronin, 1985), at least in the short term. On the other hand, cortisol levels in outside-housed sows are reported to be higher than in indoor group-housed sows, but lower than in tethered sows (Barnett *et al.*, 1985).

Metabolic changes associated with stress have also been reported in tethered animals. Higher plasma glucose and lower plasma urea concentrations were measured in gilts kept in tethers compared to gilts kept indoors in stalls or in groups (Barnett *et al.*, 1985, 1989; Cronin *et al.*, 1986). However, there is no evidence of marked differences among immune or opioid responses of sows housed in different housing systems (Barnett *et al.*, 1989; Von Borell *et al.*, 1992; McGlone *et al.*, 1994; Broom *et al.*, 1995; Tsuma *et al.*, 1996; Zanella *et al.*, 1998; Pol *et al.*, 2002). Aversive stimuli may activate the cardiovascular system but basal heart rates of sows are not influenced by the housing system. In return, heart rates during feeding are greater in sows housed in stalls than in those housed in small groups (Marchant *et al.*, 1997), and tethered sows show higher heart rates after feeding than sows kept in stalls (Schouten and Rushen, 1992).

During the peripartum and lactating periods, the farrowing crate is the dominant form of housing in pig production. It has been suggested that sows in crates may experience psychological stress as a result of prevention of nest building and/or absence of adequate material to perform it (Vestergaard and Hansen, 1984; Cronin *et al.*, 1991). The restlessness observed in crated sows during parturition and early lactation is even higher when animals have previously been housed in groups during gestation (Boyle *et al.*, 2002). For instance, according to some authors, housing conditions in intensive production might increase the incidence of savaging by preventing peri-partum social isolation (Luescher *et al.*, 1989) and nest building (Smith and Penny, 1986). However, small-scale experiments did not show a reduction of savaging with the provision of straw (Hansen and Curtis, 1981; McLean *et al.*, 1998). Furthermore, there is no evidence that the higher cortisol concentrations of sows housed in crates as compared with straw-bedded pens extend beyond the end of parturition and no effect of housing on cortisol levels has been found between the first and third weeks of lactation (Cronin *et al.*, 1991; Lawrence *et al.*, 1994). In contrast, higher cortisol levels were reported in stalled sows compared with penned sows by the end of the fourth week of lactation. This physiological indication of stress was associated with a persistent closeness of the litter (Cronin *et al.*, 1991) and corroborates changes in sow behaviour indicative of attempts to avoid the increased attention given by the piglets (De Passillé and Robert, 1989). A variety of indoor and outdoor farrowing systems have been developed, based on increased freedom for the sow, environmental enrichment and regrouping of sows and piglets (Phillips and Fraser, 1993; Marchant, 1997; Svendsen and Svendsen, 1997; see also chapter 4 in this book), but further research is required to evaluate their impact on the physiological stress responses of the animals.

The housing of sows during their development is also a key point. Indeed, it has been shown that the environment in which gilts are reared prior to breeding could have an effect on their ability to adapt to or cope with their future housing environment in gestation. Janssens *et al.* (1995) reported increased circulating cortisol concentrations during three oestrous cycles after tethering in gilts previously kept in groups, whereas cortisol concentrations remained unaltered among gilts kept in a loose housing system for the entire experimental period. In contrast, McGlone and Fullwood (2001) reported no difference among endocrine and immune parameters of gilts reared either indoors or outdoors during their development and then moved into individual gestation crates.

6.2. Social factors

The design of individual stalls may have an impact on the magnitude of the chronic stress response of sows. Indeed, a stronger response has been measured in sows housed in tethers or stalls allowing reduced visual and tactile contacts with neighbours (Barnett *et al.*, 1987a, 1989; 1991; Janssens *et al.*, 1994). For example, vertical bars lead to higher plasma cortisol levels in tethered sows compared to group-housed pregnant sows, whereas no difference was seen when bars were covered with steel mesh. Similarly, sows housed in stalls equipped with vertical bars or in groups showed lower basal cortisol concentrations than animals tethered or housed in stalls equipped with horizontal bars. These results have been associated with unresolved aggressive behaviour, which can have detrimental effects on welfare.

The disruption of normal social contacts because of unresolved conflicts or social isolation is associated with impaired welfare of pregnant sows in individual housing systems. However, the animals in group-housing systems can also be exposed to stress, resulting from social rank and aggressive interactions at mixing or during feeding. Weaned sows mixed in small groups showed small increases in cortisol on the day of grouping, independently of their social rank (Pedersen *et al.*, 1993; Tsuma *et al.*, 1996). In contrast, an effect of social rank has been reported in dynamic and large groups, where submissive sows showed higher concentrations of cortisol and more responsiveness to an ACTH challenge (Mendl *et al.*, 1992; Zanella *et al.*, 1998). Impaired welfare of gestating sows housed in groups can also be associated with body injuries induced by feeding competition or mixing, especially when social changes are done repeatedly as seen in dynamic groups (see section 4). The design of feeders or feeding areas may also have an impact on the level of stress of sows. For example, feeding stalls with solid partitions and/or increased feeder space allowance may reduce the level of cortisol and improve the immune response of sows (Barnett *et al.*, 1987a,b, 1992). Obviously, these results show advantages and disadvantages of stalls and group housing systems. Innovations such as turn-around stalls for individually housed sows, social stability, and limited feeding competition within groups may contribute to reduce stressful events and thus improve welfare during gestation.

6.3. Environmental factors

Environmental disturbance may also be a cause of stress and fear in sows. Indeed, it has been suggested that interference by humans or unfamiliar noises around parturition may increase the incidence of savaging (Smith and Penny, 1986; Luescher *et al.*, 1989). Although human disturbance before farrowing appears to increase the likelihood of piglet-directed aggression, the results of a recent study were not significant (Harris, 2002). Continuous light in the farrowing room on the other hand, reduced piglet-savaging deaths, which may be explained by a reduction of fear and alarm towards neonates (Harris, 2002).

From the above evidence, it appears clearly that sow welfare depends on a multitude of factors that belong to both the physical and the social environment of the animals. Welfare problems arise from feeding pregnant sows concentrate diets and efforts should be made to offer sows bulky diets or roughage. Care must be taken to provide animals with adequate space, flooring and temperature, to ensure comfort and health. Group housing of sows, as opposed to stalls, has the potential to improve welfare, but the social environment of sows must be managed with care in order to avoid problems relating to feeding competition and aggression at mixing. Finally, with regard to sow welfare during lactation, further research is required to evaluate alternative housing systems.

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Chapter 4. The welfare of piglets

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Abstract

With reference primarily to the 'Five Freedoms' defined by the Farm Animal Welfare Council (London, UK), the present chapter reviews the behavioural and physiological welfare requirements of domestic piglets from birth until weaning: (1) comfort and housing requirements; (2) nutrition and welfare; (3) viability and health; (4) behavioural needs; and (5) fear, stress and suffering. The general aim is to evaluate the effects of housing and management practices on the biological responses (behaviour, physiology, health, performance) of piglets in relation to their needs. Suitable and practicable modifications are put forward for the improvement of welfare under commercial production conditions. Whereas serious welfare problems directly caused by nutrition and disease are less prevalent because of their obvious and immediate economic impacts, some welfare impairments still occur that result from psychobiological suffering and insufficient attention to the comfort requirements and behavioural needs of piglets. Some of the aspects that can help to improve the piglet welfare are discussed in this chapter. High mortality of piglets after farrowing is a major problem. This can be countered by ensuring adequate design of the farrowing environment to minimise the risk of crushing, by providing an optimal thermal environment and sufficient and comfortable lying space for all piglets, and by increasing supervision at farrowing and during the suckling period. The detrimental effects of tail docking, teeth resection and castration on welfare can be diminished by modifying or improving the techniques themselves; by using analgesic protocols; and by promoting the development of general and local anaesthetics that alleviate both acute and chronic pain. The abrupt weaning of piglets has been linked to many critical aspects of welfare (e.g. aggression, rearrangement of environment and feed) which can be improved by implementing a more gradual weaning process using sow-controlled systems and/or mixing of piglets prior to weaning. In addition, these alternative housing practices combined with environmental enrichment allow the animals to display more of their natural behavioural repertoire and to experience various stimuli which can help to prevent boredom and behavioural disorders.

Keywords: *Sus scrofa,* piglets, welfare, behaviour, housing

1. Introduction

Knowledge of the welfare requirements of domestic piglets is crucial for at least three reasons. First, ensuring an adequate standard of welfare is essential for ethical and biological reasons and prescribed by the animal protection laws that exist in many countries. Second, because piglets are initially dependent on maternal care, the slightly different welfare requirements of mother and offspring must be considered simultaneously (Chapter 3). Third, basic mistakes made in establishing adequate welfare conditions for very young animals such as piglets can not only negatively affect their current condition but also interfere with subsequent 'normal' development (Chapter 5). Clearly, to an increasing extent, all of these aspects have economic implications for animal breeders in our society.

The present chapter deals with the biological background of piglets' welfare with reference to the 'Five Freedoms' formulated by the Farm Animal Welfare Council (FAWC, London, UK): freedom from (1) thirst, hunger and malnutrition; (2) discomfort; (3) pain, injury and disease; freedom to (4) express normal behaviour; and freedom from (5) fear, stress and suffering (review by Webster, 1998). These freedoms have been adapted slightly to address the main welfare issues, especially those related to commercial pig production. This chapter first describes the primary comfort and housing requirements of piglets followed by some welfare concerns related to suckling behaviour and supplemental nutrition. Because piglet mortality is still a major breeding problem, factors affecting the viability and health of piglets are also reviewed briefly. In addition, based on the behaviours observed under natural and semi-natural conditions, relevant behavioural and social needs of domestic piglets are described and corresponding requirements for enriching their housing environment are outlined. Finally, a number of welfare problems caused by fear, stress or suffering associated with common management and housing procedures are discussed briefly.

This chapter provides a concise review of the behavioural and physiological welfare requirements of domestic piglets from a bio-behavioural perspective with the aim of suggesting solutions for improving piglet welfare. Since all aspects of piglet welfare cannot be discussed in detail here, readers may wish to consult some of the many references cited in the text to obtain additional information on this topic.

2. Comfort and housing requirements

After farrowing, sows and piglets are usually housed close together during the lactation period, which makes it necessary to consider the welfare requirements of both sows and piglets simultaneously. The farrowing crate is the predominant form of housing used for farrowing sows and their litters during lactation. This system was developed in order to reduce the problem of high piglet mortality, which ranges from 11% to 26% in the various farrowing accommodations, and to reduce the space, care and costs associated with intensive housing conditions (Barnett *et al.*, 2001). There are several, often interacting, factors involved in neonatal mortality, such as crushing or physical injury caused by the sow, hypothermia, malnutrition, underweight, stunted growth and diseases. Besides meeting the welfare needs of sows, a major challenge in designing suitable housing systems for both sows and their piglets involves reducing piglet mortality and giving adequate consideration to comfort and housing requirements for piglets.

2.1. Thermal environment

Among the variables influencing the welfare of neonatal piglets, the thermal environment is one of the most important factors to consider. Newborn piglets are precocial, which means they are able to stand and walk and they have functional visual, auditory and olfactory senses. However, they have low body fat and energy reserves, a lack of coat hair, a large surface area to body mass ratio and an insufficient ability to thermoregulate after birth (Herpin and Le Dividich, 1995). Neonates therefore have an urgent need for a thermoneutral environmental temperature. The comfortable air temperature range for newborn piglets is 32 °C to 37 °C, but the comfort range decreases gradually with increasing age (Figure 1). Lower than recommended temperatures cause substantial mobilisation of energy stores, such as glycogen in the liver and skeletal muscles, with negative effects on the growth rate (Le Dividich and Noblet, 1983). Hypothermia in newborn piglets also has detrimental health effects, increasing the incidence of various diseases and ultimately contributing to increased mortality (Aumaitre and Le Dividich, 1984; Geers *et al.*, 1989). The construction of farrowing nests therefore requires the provision of an optimal environmental temperature as well as sufficient and comfortable lying space for all piglets. In indoor systems, these requirements can be met by using heat lamps and heated mats, floors or waterbeds in the creep area. The use of waterbeds may be favourable, because they provide both warmth and a flexible surface with a higher contact area for the piglets, comparable to the belly of the sow (Hoy and Ziron, 1998). In outdoor systems, depending on the geographic region, farrowing huts may need additional insulation to avoid extensive cooling during winter and overheating in summer.

2.2. Flooring

Welfare requirements for sows and piglets include comfortable, dry and safe flooring. Traumatic injuries to the limbs and feet of piglets have been reported as a common problem in many piggeries. These lesions have been observed in the first days of

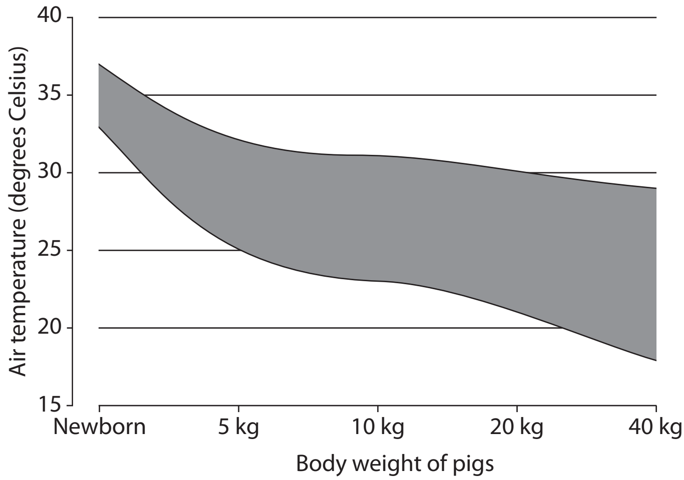

Figure 1. Recommended air temperature ranges within the comfort zones of indoor-housed pigs. Data are adapted from Wathes et al. *(1983).*

life and increase during the first week. Skin abrasions and sole bruising are thought to be related to floor surface characteristics such as abrasiveness and firmness. The prevalence of skin lesions was found to be similar for solid concrete and rubber mats, which were generally intended to improve comfort conditions. Concrete floors caused higher numbers of small wounds, whereas rubber mats resulted in deeper and larger wounds (Gravås, 1979). The incidence of sole bruising was higher on mesh floors, and the prevalence of skin abrasions was higher with mesh floors, wood shavings and uneven surfaces (Mouttotou *et al.*, 1999). On slatted floors, slot width is a matter of concern for piglet safety; slot width must not exceed 10 mm because of the risk of piglets' legs becoming trapped and the associated claw damage (see EU guideline: Commission Directive 2001/88/EC). In addition, the sharp edges of slats or the shape of mesh floors can cause extensive damage to the legs. Secondary infections associated with such leg injuries can impair the piglets' health and increase morbidity.

Skin lesions can be successfully reduced by covering the floor with polyester velour (Phillips and Pawluczuk, 1995), by using cushioned flooring (Phillips *et al.*, 1995) or by providing sparse or deep straw (Mouttotou *et al.*, 1999). In conclusion, flooring characteristics substantially affect the comfort and health of sows and piglets during lactation, and the use of adequate flooring types and bedding material therefore helps to improve their welfare.

2.3. Alternative housing

Under semi-natural conditions, newborn piglets stay in the farrowing nest during a period averaging 10 days (Jensen and Recén, 1989). After a few days, the piglets begin to follow their mother on short excursions, which is when they also have their first social contact with other piglets and animals in the group. During the ensuing period and up to the age of 7 to 8 weeks, the piglets have increasing contact with and are integrated into the group.

In contrast, in intensive systems the majority of sows and litters are individually housed in farrowing crates, which are primarily designed to reduce the likelihood of accidental crushing of the piglets (Barnett *et al.*, 2001). After lactation periods of generally 2 to 4 weeks, piglets are usually abruptly separated from the sow. Several objections concerning the welfare of both sow and piglets have been raised in relation to intensive systems. During lactation, the sow cannot get away from the piglets and their suckling attempts. Under semi-natural conditions, this is the time when the sows' maternal investment declines because of reduced suckling frequency and presence in the nest (Puppe and Tuchscherer, 2000). The abrupt weaning process also causes substantial problems for the piglets, which are confronted with maternal deprivation, nutritional changes, new housing conditions and unfamiliar piglets at the same time. Alternative indoor and outdoor housing systems try to mimic some of the conditions characterising semi-natural environments in order to improve the welfare of sows and piglets.

2.3.1. Farrow-to-finish housing

In order to reduce the problems associated with conventional weaning procedures, piglets can be raised as a group from birth to slaughter in the same pen. The underlying idea is that stress around weaning can be minimised, and later stress caused by regrouping is avoided. To achieve this, the sow is removed from the farrowing pen at weaning, but the litter remains in the pen during the ensuing growing period. It has been shown that newly weaned piglets appear to have more problems coping with a new housing environment than coping with a changed social environment (Puppe *et al.*, 1997). The avoidance of environmental and social disturbances, such as transport and mixing, has been found to result in higher weight gains, less lesions caused by aggressive interactions, improved cellular immunity and reduced salivary cortisol levels after weaning, indicating beneficial effects on performance, health and welfare (Ekkel *et al.*, 1995).

2.3.2. Sow-controlled housing

In sow-controlled housing systems, pens are typically divided into two different areas, the nest area, which is shared by the sow and the piglets, and a restricted area to which only the sow has access by stepping over a piglet-proof barrier (Pajor *et al.*, 1999, 2002). This allows sows to regulate suckling rates as they might do under natural conditions by reducing the time they spend close to their litters. In these systems, the increasing absence of the sow from her litter seems to encourage the piglets to consume more creep feed prior to weaning, while also reducing suckling frequency. Although the proportion of creep feed intake was higher than in confined pens, the weight of the piglets at weaning was lower, indicating that pre-weaning growth is still mainly dependent on milk intake (Puppe and Tuchscherer, 2000; Pajor *et al.*, 2002). Nevertheless, piglets from sow-controlled systems seem to be better prepared for the nutritional changes that occur at weaning. Pajor *et al.* (1999) found that during the first 2 weeks after weaning, at 35 days of age, piglets consumed more feed and gained more weight than piglets from confined pens.

2.3.3. Group housing

Alternative housing for sows and litters often comprises farrowing and rearing in groups under indoor and outdoor conditions. Indoor group farrowing systems usually consist of several individual farrowing pens that give sows access to a common area (Figure 2). The grouping of litters or access for piglets to a communal area is normally implemented when the piglets are between 10 and 14 days of age, a timing similar to when the sow and her offspring join the group under natural conditions. Allowing piglets from different litters to mix before weaning can be achieved by removing the piglet-proof barriers from the farrowing boxes in group housing systems or by removing the divisions between farrowing crates in individual housing systems. Modifications of group housing systems can include an additional sow-proof area for the piglets where substrate, creep feed and water are provided (Bünger, 2002). Even more natural housing conditions are provided by the Family Pen System, which allows breeding sows and growing pigs to live together in family groups (Stolba and Wood-Gush, 1984; Wechsler, 1996) and by outdoor systems with farrowing huts or shelters and access to pasture.

2.3.4. Mixing before weaning

In order to reduce aggressive behaviour among unfamiliar piglets at weaning, piglets can be allowed to mix during lactation. This procedure offers potential welfare benefits (Pitts *et al.*, 2000). Mixing at this early age also affects the feed consumption and growth rates of piglets before and after weaning. Whereas some authors found no effect on feed

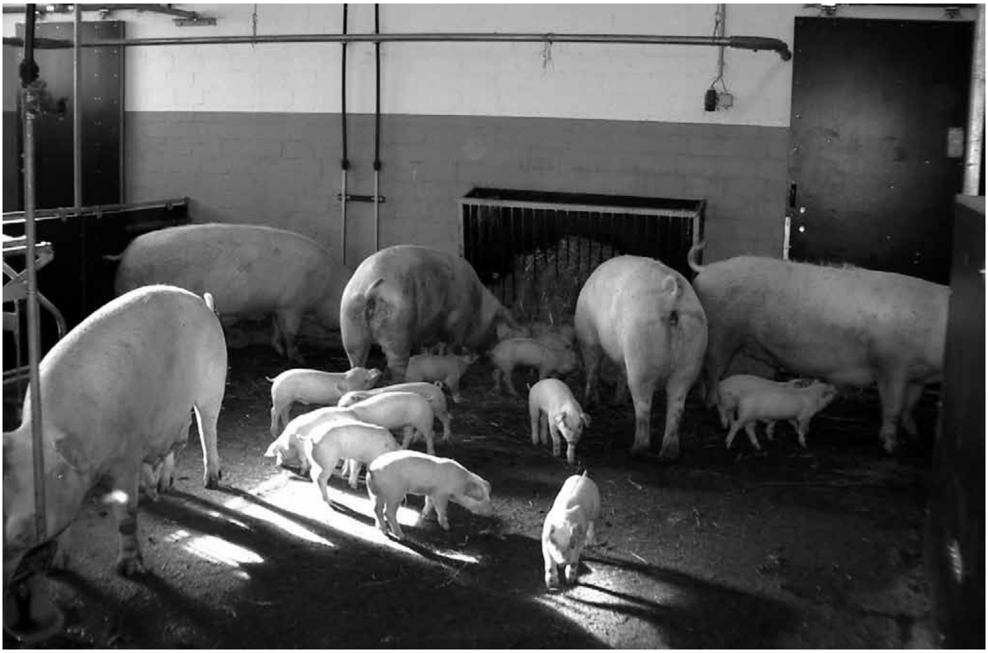

Figure 2. Group housing system of lactating sows together with their piglets (photo by K. Reiter and B. Bünger, FAL Mariensee, Germany).

intake and weight gain before weaning (Pluske and Williams, 1996a; Weary *et al.*, 1999), in a study by Weary *et al.* (2002) higher consumption of creep feed was observed, but weight gain was negatively affected. This is probably due to lower nursing frequency in pre-mixed piglets compared to control piglets (Weary *et al.*, 1999). Pre-mixed piglets ate more feed during the post-weaning period, and this higher feed consumption was also reflected in higher weight gains (Weary *et al.*, 1999, 2002).

In summary, sow-controlled systems and pre-mixing of piglets prior to weaning have certain production advantages for piglets, resulting in higher feed intake and less growth setback at weaning. Early mingling with piglets from other litters can improve the welfare of piglets, because it reduces aggression at weaning, a time when the animals are exposed to numerous stressors, such as changes in housing conditions, penmates and nutrition. Mixing during lactation also gives the piglets more space and the opportunity to become gradually acquainted with various new stimuli other than their mother and home pen. In addition, this is when they come in contact with piglets from other litters under free-ranging conditions, enabling them to display more of their natural behaviours.

3. Nutrition and welfare

A nutritionally adequate diet and drinkable water are fundamental requirements for maintaining the vitality, health, welfare and body development of neonatal piglets. This section focuses solely on problems of nutrition that are closely related to welfare in neonatal piglets. For a broader overview of general aspects of piglet nutrition, see Pluske *et al.* (1995). Pigs are iteroparous (i.e. multiple breeders) and polytokous mammals, with the sow giving birth to a number of precocious young that begin competing for nutritional and other resources early on. It is clear that the main nutritional resource in the first weeks after birth is the milk normally provided by the piglets' mother. As an adaptive consequence, pigs have developed a very characteristic pattern of nursing and suckling behaviour whereby the milk is distributed among a number of littermates (review by Fraser, 1980). With increasing age, and therefore increasing independence from direct maternal care, piglets in commercial pig production are offered pre-weaning creep feed mainly to support the abrupt nutritional change from liquid (milk) to solid feed after weaning. Because pigs have evolved a reproductive system characterised by slight overproduction of young (review by Puppe, 2002) the main nutrition-related welfare issues of neonatal piglets are connected with their behavioural strategies of milk intake (suckling) to avoid malnutrition and, therefore, to improve their chances of survival and to thrive in a context of social cooperation and mutual competition. Indeed, English and Smith (1975) attributed 43% of piglet deaths to the failure of apparently normal piglets to achieve adequate nutrition by suckling.

3.1. Colostrum and milk intake

It is widely accepted that the piglet's weight at birth is the main factor determining survival during the first critical days and the achievement of a satisfactory weaning weight. Other important determinants have been identified as foraging behaviour of neonates, their thermoregulatory capacity and litter size (Tuchscherer *et al.*, 2000). Newborn piglets with early and sufficient colostrum and milk intake generally show improved survival rate, health and subsequent growth (Tuchscherer *et al.*, 2000). Early and adequate intake of colostrum and milk is crucial for the development of immune protection (Wilson, 1974) and as a source of energy to prevent hypoglycaemia and heat loss (Le Dividich and Sève, 2001). This is a major welfare concern because neonatal piglets initially need the passively transmitted immune protection from the mother's milk for disease protection, and because they have an insufficient ability to maintain homeothermic balance. The transition from colostrum to mature milk is characterised by decreased protein content largely because of the decreased immunoglobulins (Klobasa *et al.*, 1987). This situation relates to welfare and may result in higher piglet mortality and lower vitality. Piglets that die have lower levels of immunoglobulin G, whereas piglets with higher levels have started to suck sooner and have won more of their teat disputes (De Passillé *et al.*, 1988).

Le Dividich and Sève (2001) reviewed the energy requirements of the young pig based on several studies. They concluded that in the suckling piglet the metabolisable energy (ME) requirements for maintenance (including the energy cost of basal metabolism, physical activity and thermoregulation) can be estimated at about 470 kJ ME kg^{-1} $BW^{0.75}$ per day (see also Jentsch *et al.*, 1995). It has also been shown that environmental temperature can have detrimental effects on milk intake in piglets both directly, when they are subjected to cold stress at birth (Le Dividich and Noblet, 1981), and indirectly, through the reduced milk yield of the sow at high temperatures. The data on the milk intake of a piglet per successful suckling bout show a wide range, from 10 g to 60 g, but a milk intake of about 30 g is considered typical (Pluske and Williams, 1996b; Puppe, 2002). The whole nursing-suckling interaction of sow and piglets, however, is a complex behavioural and physiological process, which is evolutionarily equilibrated between the different interests of mother and offspring. As a consequence, piglets distribute themselves at feeding along the sow's udder in a 'teat order' (McBride, 1963) in which each piglet consistently sucks from one teat or teat pair until weaning (Hoy and Puppe, 1992). The highest daily suckling frequency and the highest suckling stability (teat fidelity) occurred in the second week of life, followed by the highest milk intake around the third week (Figure 3). The proximate welfare advantage lies in reduced competition and fighting among the young at the udder, supporting maximised milk intake. More generally, these patterns may be viewed as strategies of suckling behaviour that have evolved to exploit the best nutritional supply from the mother and they may also be regarded as an adaptive response of piglets to the first maternal attempts to start the weaning process (Puppe and Tuchscherer, 2000). Additionally, piglets suckling at the preferred anterior teats may have some fitness-related advantages compared with their littermates suckling at the posterior teats: they have a higher milk intake (Pluske and Williams, 1996b) and a higher weight gain and attain higher positions in the dominance hierarchy after weaning and mixing (Puppe and Tuchscherer, 1999).

From a more practical standpoint, welfare impairments related to suckling behaviour can be attenuated by avoiding high environmental noise levels which disturb communication during suckling (Algers and Jensen, 1985), extremely large litter sizes (Hartsock and Graves, 1976) and excessive quantities of milk supplements (Vaillancourt and Tubbs, 1992). In addition, providing biologically relevant stimuli (e.g. sand and straw) can improve some elements of suckling behaviour that might be advantageous for early milk intake in piglets (Herskin *et al.*, 1999).

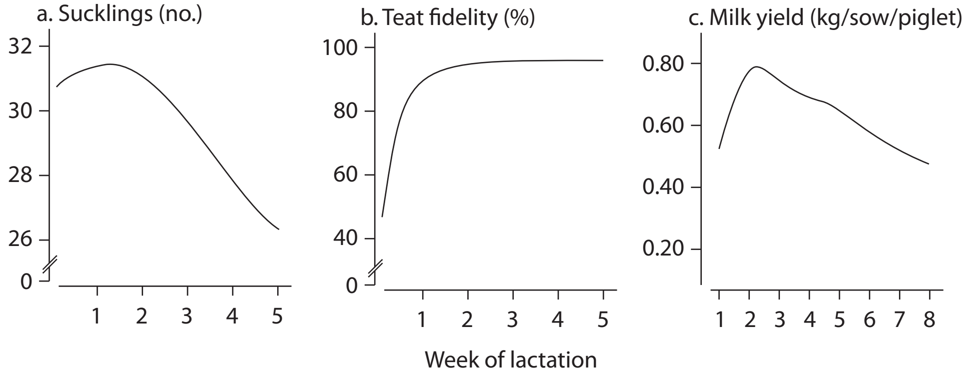

Figure 3. Development of daily number of piglets' suckling bouts with milk intake (A), their teat fidelity (B) and sows' milk yield (C) during lactation. Data (B, A) are adapted from Puppe and Tuchscherer (1999, 2000) and (C) Niwa et al. *(1951).*

3.2. Creep feed and water intake

In current agricultural practice, suckling piglets are offered supplemental solid feed and water. Whereas piglets begin to drink water some hours after birth, with a more or less continuous daily increase (Fraser *et al.*, 1993), noticeable creep feed intake occurs only from the third or fourth week after birth (Figure 4). Admittedly, both forms of nutritional intake show considerable intra-litter and inter-litter variation in terms of beginning and daily quantity (Pajor *et al.*, 1991; Appleby *et al.*, 1992; Fraser *et al.*, 1994).

Although water intake and solid feed intake in suckling piglets normally do not present serious welfare problems, a little more practical and scientific attention might be useful. For instance, it seems that very young piglets try to compensate for incipient dehydration by increasing their water consumption, especially when malnutrition (e.g. poor milk provision by the sow) is combined with high environmental temperatures (Fraser *et al.*, 1993). In such cases, excessive early drinking may serve as a secondary indicator for other existing welfare problems. Recently, several studies involving a sow-controlled housing system have shown some welfare benefits for piglets when they have access to a communal creep area. Such piglets eat more and suffer less growth setbacks at weaning, and they continue to eat more and gain more weight after weaning (Weary *et al.*, 2002). This is also important because regular and adequate post-weaning feed intake can reduce the risk of digestive disorders (Madec *et al.*, 1998). Although the use of a better quality diet (e.g. a 'high-complexity' diet with higher crude protein and fat content) tends to increase the average feed intake by the young

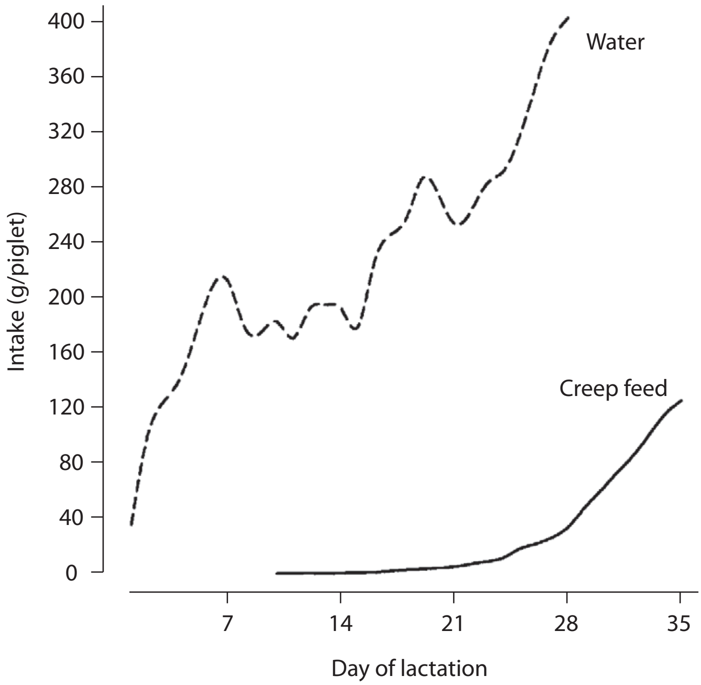

Figure 4. Development of daily creep feed consumption (provided from day 10 after birth until weaning at day 35) and water intake (provided from day 1 after birth until weaning at day 28) in suckling piglets during lactation. Data (water) are adapted from Nagai et al. *(1994) and (creep feed) Puppe and Tuchscherer (2000).*

and the weight gain immediately after weaning, individual variation remains very high and considerable improvements in adaptation to weaning appear rather doubtful (Fraser *et al.*, 1994, Pajor *et al.*, 2002). Overall, it seems that the major advantage of providing creep feed lies in expanding piglets' feeding experience beyond than suckling (Delumeau and Meunier-Salaün, 1995), and in the tendency of this feed to increase piglets' weaning weight (Fraser *et al.*, 1994) supporting, thus, piglets in the process of transition to weaning.

At weaning, there is a change from complete nutritional and behavioural dependence on the dam to complete independence necessitating very different feeding and drinking patterns. This stressful time may be accompanied by reduced digestive and absorptive capacity of the intestine and elevated health problems (e.g. diarrhoea), affecting the welfare of the weaned piglet (Pluske *et al.*, 1995). Nearly all health problems of newly weaned piglets are caused by intestinal microbes of the gut flora

(Bolduan *et al.*, 1988). Commercial feeding programs are therefore normally designed to overcome the post-weaning growth setback, to facilitate voluntary feed intake and to improve productivity, which may also have benefits for the maintenance of animal welfare. A relatively new area of human and experimental animal research deals with the potential effects of early 'nutritional programming' ('metabolic imprinting') on subsequent physiological and genetic imbalances which may contribute to a higher risk of suffering stress or disease susceptibility (Waterland and Garza, 1999). For instance, it has been shown recently that a restricted protein diet (soy protein isolate vs. casein) fed to growing pigs resulted in the increased expression of genes involved in the oxidative stress response (Schwerin *et al.*, 2002). Future research in this area is needed to understand the underlying mechanisms and to avoid potentially negative effects on the health and welfare of the animals.

Finally, apart from their nutritional value, both water and solid feed can also be used as carriers for several additives designed to adjust nutritional imbalances (e.g. vitamins), to prevent or medicate diseases (e.g. antibiotics, trace elements) and to increase performance (e.g. growth promoters). However, the unlimited, permanent or long-term use of feed additives intended especially to promote the growth of the animals but originally thought to prevent diseases or to avoid health problems poses risks in terms of promoting antibiotic-resistant genes. In addition, this approach is detrimental to animal welfare and will be increasingly forbidden by law (review by Kan *et al.*, 1998).

4. Viability and health

Low piglet viability is partly related to intrinsic causes tied to the physiological status of the animal (low birth weight) or internal health disorders (e.g. splayleg, enteritis). The majority of deaths occur during the first 3 days (up to 80%) with at least 50% occurring during the first day (Barnett *et al.*, 2001). Early piglet mortality is mainly the result of crushing, but intrapartum stillbirths, underweight, malnutrition, starvation and chilling are other important causes of death.

4.1. Mortality

Minimising neonatal mortality and morbidity in farm animals is a major animal welfare concern (Mellor and Stafford, 2004). Viability at birth may depend on the farrowing process, with a prolonged delivery increasing the risk of abnormal asphyxia and lower viability in newborn animals, which are less likely to adapt to extra-uterine life (Herpin *et al.*, 1996). Compared with their relatively inferior littermates, piglets with well-developed physiological (e.g. high birth weight, low drop in rectal temperature) and behavioural (e.g. short latencies of standing up, udder contact and colostrum intake) features are characterised by lower mortality, higher weight gain during the suckling period and successful competition as indicated by the preferred use of the cranial teat pairs (Hoy *et al.*, 1995).

In the immediate postpartum period, the provision of warmth promotes survival by reducing the risk of chilling leading to deep hypothermia and inanition (Herpin and Le Dividich, 1995). The establishment of regular colostrum and milk intake also plays an important role for the piglets' survival rate and health (Tuchscherer *et al.*, 2000). Consequently, the supervision of farrowing and the provision of assistance to piglets consist mainly in removing the placenta envelopes around the piglets to prevent suffocation, providing sow colostrum to low-birth weight piglets and positioning weak piglets in the heated area, which can improve their survival (Figure 5).

As with indoor conditions, crushing is the most common cause of death under outdoor conditions, affecting more than 70% of liveborn piglets (Edwards *et al.*, 1994). The piglets are more vulnerable to crushing during the first 3 days after farrowing when they spend much of their time near the udder and have relatively poor mobility. The risk of being crushed by their own mother increases in starved or poor weight-gain

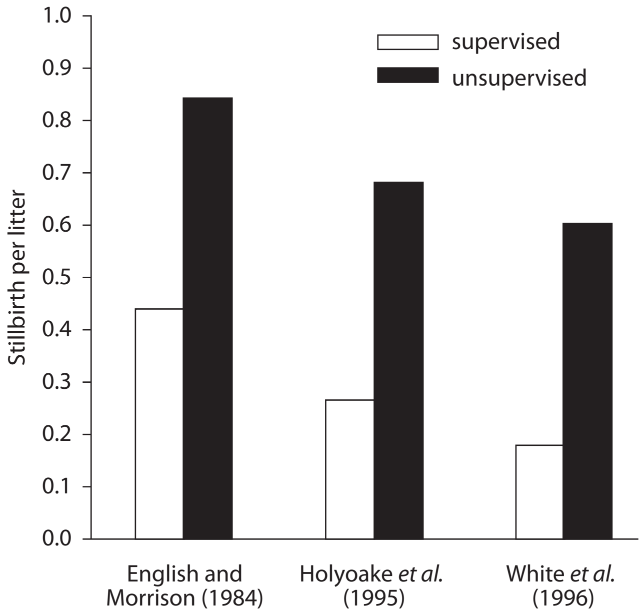

Figure 5. Incidence of supervision of farrowing on stillbirths (Data are adapted from English and Morrison, 1984; Holyoake et al.*, 1995; White* et al.*, 1996).*

piglets as a direct result of more risky feeding behaviour. Indeed, they have a higher need for nutritional supply from the mother (e.g. because they have missed a milk ejection) and they are forced to spend more time in proximity to the sow and therefore have a higher risk of crushing mortality (Weary *et al.*, 1996b). These piglets are able to express their impaired well-being through vocalisation, for instance. They use more, longer and higher frequency calls than their unimpaired littermates (Weary and Fraser, 1995). Such calls may be classified as stress vocalisations and they can easily be used for an immediate evaluation of the current state of the individual under various housing and feeding conditions (Schön *et al.*, 2001).

Farrowing crates are designed to restrict body movements by the sow that are potentially harmful to the piglets, e.g. lying down from a standing or sitting position, rolling from lying on side to lying on udder and vice versa (Weary *et al.*, 1998a; Marchant *et al.*, 2001; Vieuille *et al.*, 2003). The impact of body movements in relation to crushing depends on the design of the farrowing environment, with more deaths caused by rolling in the pen than lying down in the crate (Weary *et al.*, 1996a). A crate fitted with horizontal bars improves the way sows lie down and therefore helps to protect and ensure the safety of piglets. The risk of crushing has been shown to be reduced through the provision of environmental stimuli relevant for nest building (Pedersen *et al.*, 2003). They can aid in ensuring that fewer piglets are born before the last postural change during farrowing (Thodberg *et al.*, 1999) and they can encourage higher sow responsiveness to piglets' distress calls (Wechsler and Hegglin, 1997; Herskin *et al.*, 1998). However, the causes of high crushing mortality depend on numerous characteristics of the sow and the litter, including high parity, individual sow behaviour, large litter size, low birth weight and early weight gains (Wechsler and Hegglin, 1997; Weary *et al.*, 1998a; Ahlström *et al.*, 2002; Valros *et al.*, 2003). Survival of the piglets during the first days of life can be compromised by the sows' ability to move freely in the farrowing pen (Jarvis *et al.*, 2005). This points up the difficulty of ensuring the welfare of both sow and piglets during the peripartum period. One possibility for reducing piglet losses by crushing is the temporal confinement of sows in crates for a few days after parturition (Stabenow and Manteuffel, 2002).

Figure 6 summarises the major risk factors related to the viability and health of piglets after farrowing. In conclusion, piglet survival can be improved by providing a suitable design for the farrowing environment in order to reduce the risk of crushing and by increasing supervision at farrowing and suckling, as well as by providing additional care for weak animals to maintain good health and nutritional status in piglets.

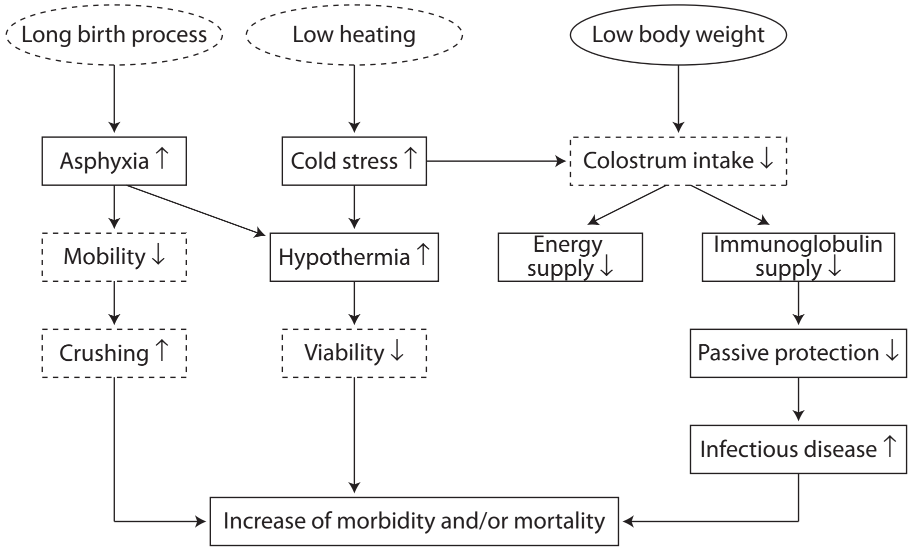

Figure 6. Schematic representation of some major risk factors affecting the morbidity and mortality of piglets around farrowing (adapted from Herpin et al.*, 1996; Le Dividich* et al.*, 1998; Barnett* et al.*, 2001). The arrows indicate the increase/decrease of factors associated with physiological mechanisms (solid lines) or rather with behaviour-related processes (dashed lines).*

4.2. Disease prevention

Deficiency diseases are usually a farm problem rather than a specific problem affecting individual piglets, and they can span the whole spectrum of nutrients. Disease prevention aims to limit deficiencies in energy and protein feed that can lead to growth and muscle development problems, in water linked to salt poisoning, in iron leading to anaemia and also to poor performance and death, in B vitamins related to skin and foot problems, and in other minerals or vitamins associated with various health disorders (Bernhoft *et al.*, 2002). Clearly, the effects of these deficiencies interact with housing conditions. Indeed, iron injections for preventing anaemia in neonates and improving their survival may be unnecessary for outdoor piglets because of iron availability in the soil (Brown *et al.*, 1996; Egeli and Framstadt, 1999). Splayleg can result from a combination of marginal vitamin deficiency, low birth weight, slippery floors and crowding (Iben, 1989), whereas the development of lesions on piglet legs or knees is usually caused by repeated rubbing against an abrasive floor during suckling (Mouttotou *et al.*, 1999). The provision of straw bedding can prevent serious leg injuries and accelerate the healing process for injuries (Kelly *et al.*, 2000b). After weaning, the pathways for maintaining health and preventing post-weaning diarrhoea can be reached by ensuring a good hygiene level within pens and between batches, an adequate feeding regimen and reduced mixing of piglets from different groups exposed to varying levels of pathogen pressure.

In conclusion, piglet welfare can be improved by implementing disease prevention through the design of the farrowing pen and flooring, hygiene and attention devoted to the health and the nutritional status of the piglets.

5. Behavioural needs

A 'behavioural need' can be viewed as a motivation to perform species-specific behaviour caused both by internal and external factors (Jensen and Toates, 1993). Preventing an animal from performing a certain behaviour in a particular situation might cause suffering and impair welfare. Like other young mammals, domestic piglets display a number of social and non-social behaviours which ultimately developed through evolution and are proximately affected by current environmental conditions (e.g. housing, management). It is clear that knowledge of such behaviour patterns has been derived mainly from studies under natural or semi-natural conditions. The incorporation of key environmental and behavioural features into commercial housing systems may lead to considerable welfare improvements (see Stolba and Wood-Gush, 1984).

5.1. Social behaviour

Pigs are highly social animals that live in family groups in which several sows related to each other simultaneously give birth to multiple young (Gundlach, 1968). Mutual recognition and maternal care for the offspring are a fundamental part of their social life. According to parent–offspring conflict theory, the social behaviour between mother and young piglets ultimately evolved to maximise fitness within the related members of a species (see Fraser *et al.*, 1995; Puppe, 2002). This means that the sow's interest in investing in her piglets (e.g. milk, protection) and the piglets' interest in receiving maternal care are evolutionary balanced and vary both within a lactation period and over several lactations. Depending on the existing environmental conditions, the mother gradually reduces her level of care (e.g. her readiness to nurse; Puppe and Tuchscherer, 2000) as weaning time approaches. The piglets, however, tend to stimulate their mother to obtain as much parental investment as possible (Fraser *et al.*, 1995). In modern husbandry, social interactions between mothers and piglets are limited by the confinement of sows in a farrowing crate, a situation that biases some elements of the relationship in favour of the young. This may stress the mother and also have a negative impact on the young through disturbed social and nutritional relationships. Allowing sows some control over the level of parental investment (e.g. in sow-controlled housing systems) can actually have welfare advantages for both sow and litter, given the right management conditions (Fraser *et al.*, 1995). On the other hand, alien piglets may suckle on a sow that is not the biological mother (Fraser *et al.*, 1995). Such communal rearing systems are possible for species in which related females live with their immature offspring under natural conditions. This socially adaptive behaviour is the biological prerequisite for some management and housing tools used in commercial pig production (e.g., fostering of piglets, group housing systems for lactating sows with cross-suckling of piglets), and this probably does not cause too much welfare impairment. Indeed, fostering in commercial pig production is usually applied in order to standardise the litters and to save piglets when sows are sick, have low milk yield or have too few functional teats. Fostering is also used to increase the chance of survival of supernumerary newborn piglets born to hyperprolific sows (Orgeur *et al.*, 2002). Whereas early fostering is possible within the first 2 days after birth (Vaillancourt and Tubbs, 1992), late fostering induces major behavioural disturbances in sows and piglets (Horrell and Bennet, 1981). Moreover, repeated cross-fostering at this time (e.g. used in early-weaning units) disrupts suckling patterns and impairs the welfare of sows and piglets, as evidenced by increased fighting, vocalisations, skin lesions in piglets and dam aggression toward alien piglets (Robert and Martineau, 2001).

Piglets establish two different types of social organisation: territorial teat order during early suckling (McBride, 1963) and a social hierarchy resulting from fighting for dominance after weaning (Scheel *et al.*, 1977). Immediately after birth, piglets fight vigorously with their littermates for access to the sow's teat (Fraser and Thompson, 1991) until the teat order is stable (> 90% use of the same teat) after approximately 4 days (Puppe and Tuchscherer, 1999). It should be noted that this competition plays a major role in neonatal death (Hartsock and Graves, 1976). Clearly, the establishment of stable teat preferences may be delayed if the number of piglets is higher than the number of functional teats (Orgeur *et al.*, 2002).

To establish and develop social relationships during the suckling process, piglets use nearly all of their sensory communication capacities. Olfactory, auditory, tactile and thermal cues provided by the sow are used for teat location and recognition (Rohde-Parfet and Gonyou, 1991). Additionally, piglets can discriminate between mother and non-mother odours at 12 hours of age (Morrow-Tesch and McGlone, 1990). Another very impressive feature is the characteristic pattern of grunting that sows use to attract the piglets to the udder and lead them through the several phases of a successful nursing episode (Fraser, 1980). Individual differences are expressed by the composition of the grunt frequencies (Schön *et al.*, 1999). Reciprocally, sows are able to recognise their offspring based on the acoustic cues of piglet calls (Illmann *et al.*, 2002). It has been shown that the nursing vocalisation of any sow elicits an initial generalised approach and contact response in the young, reflecting their high motivation to gain nutritional or social support (Puppe *et al.*, 2003). Close to the sound source, however, maternal vocalisation is clearly preferred. This auditory discrimination ability is already developed in very young piglets (i.e. 36 hours after birth; Shillito Walser, 1986). Consequently, any impairment of this communication process, such as by high environmental noise, can affect the appropriate social and nutritional development of the young (Algers, 1993).

At the beginning of lactation, the sow initiates nursing and after several days the piglets begin to take initiative (Fraser, 1980). Massaging of the udder, before and after suckling is necessary to trigger periodical milk output. There is some evidence that a more intensive massage increases the amount of milk received in future suckling bouts, and this can be viewed as an example of maternal manipulation by piglets whose begging behaviour is designed to increase their fitness (Jensen *et al.*, 1998; Dostálková *et al.*, 2002). Farrowing systems allowing sows more control over their behaviour lower the frequency of suckling bouts but extend the duration of individual suckling bouts, possibly leading to increased milk production (Arey and Sancha, 1996).

As reviewed by Špinka *et al.* (2001), play behaviour enables young animals to cope successfully with later unexpected situations, and it can be assumed that this behaviour is a basic necessity for their normal development. Under semi-natural conditions, social play can be observed in piglets during the first weeks of their life, particularly between 2 to 6 weeks of age (Newberry *et al.*, 1988). Besides individual traits such as scampering, hopping, pivoting and the shaking and carrying of objects, more social features like circling or trotting with other piglets are common patterns of play behaviour. Moreover, some social traits of later agonistic behaviour (e.g. biting, shoving) also have some early playful qualities, but they are difficult to distinguish from exclusive play behaviour (Newberry *et al.*, 1988). Generally, piglets have a stronger association with their familiar littermates than with any other category of herd members (Newberry and Wood-Gush, 1986). Blackshaw *et al.* (1997) have demonstrated that similar patterns of playing also occur in various indoor environments. Additionally, the motor patterns of adult boar sexual play (e.g. ritualised approach and mounting) are displayed by piglets of both sexes (Berry and Signoret, 1984). Overall, play behaviour may serve as an indicator of a high welfare standard (Lawrence, 1987).

5.2. Non-social behaviour

Under natural or semi-natural conditions, piglets display a variety of non-social behaviour patterns, including walking, sniffing, lying, rooting or standing (Newberry *et al.*, 1988) All activities are generally synchronised between nearest-neighbour piglets. During the early lactation period, piglets spend most of their time sleeping, resting and suckling. Afterwards, increased overall activity and behaviours associated with solid feed ingestion are observed (Fraser, 1978). Vital behaviours like ingestion (e.g. feeding, drinking and sucking) and resting seem not to be strongly influenced by rearing conditions (Schouten, 1986).

5.3. Environmental enrichment

Impoverishment of the environment may lead to redirected exploratory behaviour (e.g. excessive nibbling or massaging of the penmate) which is probably caused by the lack of suitable inanimate substrates. Because this is considered detrimental to animal welfare, environmental enrichment with foraging substrates or with objects may improve the biological functioning of the animals in modern husbandry (Newberry, 1995). Petersen *et al.* (1995) have shown that piglets in pens enriched with straw, logs and branches directed their exploratory activities like rooting, biting and chewing towards the material provided rather than towards unsuitable material within the pen (e.g. floor, wall) or towards social partners (e.g. penmates, sow). A more recent study has demonstrated that piglets reared in an enriched group-farrowing system are better adapted to non-social and social challenges at weaning compared to piglets reared in an enriched individual-farrowing system (Hillmann *et al.*, 2003). After weaning, the enrichment of pens with manipulable substrates or toys can also reduce aggression within groups and it increases the frequency of substrate-directed behaviours such as rooting (O'Connell and Beattie, 1999; Kelly *et al.*, 2000a).

Finally, a barren environment actually impairs various aspects of welfare and single measures of environmental enrichment are still impoverished in comparison with natural or semi-natural environments. Furthermore, enrichments must be differentiated in terms of their suitability for the behavioural needs of the animals, and the provision of substrates that allow rooting behaviour is obviously more important for the animals than the provision of rubber toys. Certainly, a key welfare improvement associated with environmental enrichment is the opportunity for piglets to display more of their natural behaviours. The expression of appropriate behavioural and mental activities can reduce aggressive behaviour, boredom, stress and the risk of injuries, without negative effects on growth performance. For example, integrating cognitive challenges into feeding can be a useful approach (Ernst *et al.*, 2005).

6. Fear, stress and suffering

Piglets exhibit fearful responses in several life contexts, e.g. when subjected to surgical treatment or manipulation, at weaning, when mixed with unfamiliar piglets or when placed in an unfamiliar environment. Difficulties that the animals have in coping with these stressful events are normally reflected in behavioural disturbances and biological stress responses. This chapter deals only with some important events causing fear and stress, specifically surgery and ablation, weaning and mixing. There are many other causes of stress in piglets. Human–animal interactions during pig production are a primary example (Chapter 10). Many practices involve visual, auditory and tactile contacts between stockpersons and the animals: the quality of these relationships can have tremendous effects on the welfare and performance of the animals. For a detailed overview on the nature and impact of these interactions, see Hemsworth and Barnett (2000) or Chapter 10.

6.1. Surgery and ablation

The routine management of tail docking, ear notching, tooth clipping and castration may pose major welfare problems leading to fear, stress and potential suffering. In current agricultural practice, tail docking has been developed to minimise tail biting, whereas ear notching is done to identify the animals. Piglets are born with fully erupted 'needle teeth', which are used in competing for access to teats (Fraser and Thompson, 1991). Producers often clip these teeth to prevent facial lacerations to penmates or damage to sows' teats. Castration of males is done for an economic purpose, that is, to prevent their meat from becoming tainted with 'boar odour'. All of these practices are usually performed soon after birth, because it has long been assumed that neonatal animals are less sensitive to pain than older ones. In light of modern animal research findings, however, these treatments produce distress and pain and can be detrimental for animal welfare.

Tail docking, teeth clipping and ear notching induce moderate but transient behavioural changes during and immediately after the procedures (Prunier *et al.*, 2002). In all cases, piglets exhibited some degree of distress as evidenced by vocalisations and struggling that began as soon as they were picked up, indicating that restraint itself is a stressor. Specific procedures gave rise to specific behaviours in piglets: tail docking caused tail jamming and wagging; ear notching caused mainly head shaking; and teeth clipping tended to cause teeth champing (Noonan *et al.*, 1994). These behavioural responses normally disappear a few minutes after the procedure, and no long-term effects on behaviour or stress hormone responses were reported (Prunier *et al.*, 2002). The effect of teeth resection on growth, damage to sow teats or facial lesions in piglets depends on procedure management. Selective or total resection within litters during the first week may cause reduced weight gain in resected piglets (Robert *et al.*, 1995; Brown *et al.*, 1996). Partial teeth clipping appears to reduce competition and biting among littermates and results in less injury to other piglets (Fraser and Thompson, 1991; Weary and Fraser, 1999). The long-term effects of tail docking on the vice of tail biting are unclear. Simonsen (1995), for instance, found no significant effects for tail docking on the frequency of tail or tail stump biting during the fattening period.

The overall results suggest that the stress experienced by the animals is not long-lasting, and there is a high degree of within-litter variation for piglets undergoing the same procedure. Nevertheless, the use of analgesics in the tail docking procedure or the use of a grinding wheel rather than cutting pliers for teeth resection can successfully reduce the behavioural and physiological changes associated with these procedures. In addition, an evaluation of the long-term consequences of tail docking and teeth clipping indicates that these procedures themselves can lead to injury or infection. Simonsen *et al.* (1991) reported the development of neuroma and increased pain sensitivity in the amputation stump. Gingivitis and pulpitis, which extended along the splinter from the apex to the root, were also reported, especially with teeth clipping versus grinding and even stronger effects if clipping is performed close to the gum line (Weary and Fraser, 1999; Prunier *et al.*, 2002).

The castration of male piglets induces major vocal and motor responses. Vocal responses of castrated piglets are characterised by more high-frequency calls (> 1 kHz), which are considered a reliable indicator of a painful event (Weary *et al.*, 1998b). Compared to sham-operated animals (which were restrained and washed but not castrated), the various invasive stages of castration (i.e. incision of the scrotum and pulling/severing the spermatic cords) produced significantly more high-frequency calling than restraint alone at the same stages of the procedure. The pulling and severing of the spermatic cords are the most painful components of castration (Taylor and Weary, 2000). Recent investigations have shown, however, that the surgical procedures during castration mainly alter acoustical measures (e.g. call duration, peak frequency, pureness and entropy of the sound), which describe vocal quality rather than quantity (Puppe *et al.*, 2005). Nevertheless, the observed changes in acoustical parameters during the surgical period of castration can be interpreted as vocal indicators of experienced pain and suffering, and this calls into question the current practice of non-anaesthetised castration of piglets. This is supported by physiological investigations which demonstrate a strong activation of the pituitary-adrenocortical stress axis in piglets undergoing surgical castration without anaesthesia and analgesia (Prunier *et al.*, 2005).

The behavioural changes that occur after castration are mostly short-term and concern mainly suckling activity and specific behaviours (McGlone and Hellman, 1988; Taylor *et al.*, 2001). Immediately after the procedure, castrated males are seen less often in a relaxed attitude and show more stiffness, huddling and prostration compared to intact penmates. Castrated animals also scratch their rump by rubbing it against the floor, a behaviour which is observed until 4 days after castration (Hay *et al.*, 2003) and which can be interpreted as a way to alleviate pain. During the first hours after castration, piglets exhibit trembling, a problem that can be reduced by the administration of a local anaesthetic pre-treatment (Hay *et al.*, 2003).

It has been assumed that neonatal animals are less sensitive to pain than older animals, and this reasoning has been used in EU legislation to stipulate that castration procedures be performed during the first week of life. However, growth depression was found to be higher after castration at very young ages (Kielly *et al.*, 1999), and vocal and behavioural responses were not affected by the age of the piglets (Taylor *et al.*, 2001). The administration of pain-relieving drugs can reduce the immediate and/or post-operative behavioural responses (McGlone and Hellman, 1988; Horn *et al.*, 1999). In addition, general and/or local anaesthetic procedures have been shown to reduce levels of blood cortisol and ACTH (Prunier *et al.*, 2002) as well as the heart rate response associated with castration. Other alternatives consist in chemical castration or active immunisation against gonadotropin-releasing hormone (Bonneau and Enright, 1995), but more research is required in order to reduce aversive effects associated with conventional adjuvants unacceptable for use in a commercial vaccine and repeated administration.

In conclusion, the detrimental effects of tail docking, teeth resection and castration on welfare should be reduced by modifying or improving the techniques, by using an analgesic protocol and by developing general and local anaesthetics designed to alleviate both acute and chronic pain.

6.2. Weaning

Weaning is a natural process that occurs gradually over several weeks in all mammalian species involving a series of transitional stages. The newly weaned piglet, however, has to cope with the challenge of abrupt nutritional independence and social integration at the time of mixing, as well as with the loss of maternal attachment (Held and Mendl, 2001). In pigs, frequency of suckling decreases after the first week, and under semi-natural conditions, weaning is completed after about 9 to 17 weeks post-partum when the piglets subsist on solid feed exclusively (Newberry and Wood-Gush, 1985; Jensen and Récen, 1989). The weaning period under semi-natural conditions is also characterised by gradual changes in the social environment. After staying in the farrowing nest for up to about 10 days, piglets start to accompany their mother and make their first acquaintance with other piglets and herd members. Their contacts with the herd increase during the ensuing period, and the piglets are fully integrated into the herd after about 7 to 8 weeks.

In intensive systems, however, piglets are abruptly separated from the sow by the breeder at an earlier age than under natural or semi-natural conditions. Mother–young separation is often performed at 3 to 5 weeks post-partum. In a recent study, weaning of piglets at 21 or 28 days of age reduced their performance and induced behavioural and hormonal changes relative to nursed piglets (Colson *et al.*, 2006). Although negative effects on growth rate and stress endocrine responses are stronger in piglets weaned at 21 days, behavioural disturbances are recorded in both weaned groups but with differing kinetics. In some instances weaning occurs as early as 1 to 3 weeks. Very early separation, at one week, is practised in France mainly with hyperprolific sows to enable their supernumerary piglets to survive and grow. Early separation (SEW: Segregated Early Weaning), between 2 and 3 weeks of age, is also practised in North America to control the spread of diseases (see also Chapter 5). Early weaning procedures cause sudden changes in social and environmental conditions, including the feeding regime. If the management and hygiene conditions do not correspond to an extremely high standard, various welfare problems can be expected (Robert *et al.*, 1999), especially those associated with the very young age of the piglets (e.g., high level of belly nosing, chewing penmates throughout the later growing phase). Indeed, Worobec *et al.* (1999) have shown that piglets weaned at 1 week displayed altered development of behaviour patterns in contrast to piglets weaned at a later age (2 or 4 weeks), e.g., they spent more time belly nosing. Additionally, there is some evidence that early weaned piglets show neuroendocrine responses (e.g. transient increase in cortisol excretion) reflecting emotional distress (Hay *et al.*, 2001). Moreover, Orgeur *et al.* (2001) reported that piglets separated at 1 week displayed behavioural disturbances such as increased vocalisations, aggressive behaviour and belly nosing, in contrast with piglets nursed by their dam. Although the causal factors of belly nosing are not completely known, it is considered a common anomalous behaviour in early weaned piglets. A recent study by Li and Gonyou (2002) suggests that belly nosing is more closely associated with social interaction than with eating or drinking and serves as a substitute for other social behaviours.

Numerous studies have shown that the practice of abrupt weaning under intensive housing conditions may cause subsequent behavioural responses that are potentially responsible for the development of serious psychobiological disturbances and welfare problems (review by Held and Mendl, 2001). For example, experimentally induced intermittent maternal deprivation and social isolation of piglets resulted in decreased emotional reactivity, increased stress hormones and suppressed immune responses (Kanitz *et al.*, 2004). Additionally, it was found that abrupt weaning is associated with growth setback, elevated levels of stress hormones and suppression of immune functions causing increased disease susceptibility (Kanitz *et al.*, 2002). Alternative housing systems seek to lessen the negative impact of abrupt weaning on piglet welfare through a more gradual weaning procedure. In sow-controlled systems, the sows can regulate nursing rates, as they might do under natural conditions, and they can decrease their maternal investment by reducing time spent with the litter. Removing the sow from the litter and keeping the litter in the farrowing pen but not introducing mixing with unfamiliar piglets can also reduce the negative consequences of abrupt maternal deprivation (see section 2.3. for more details on alternative housing). In general, weaning practices that mimic certain aspects of the natural weaning process can ameliorate some of the behavioural problems in young commercial weaners (Held and Mendl, 2001).

6.3. Mixing and aggression

The abrupt weaning of piglets in commercial pig production often comprises mixing with unfamiliar animals in a new environment, a situation generally accompanied by an increase in circulating stress hormones (Mason *et al.*, 2003; Merlot *et al.*, 2004). The establishment of a social hierarchy within the new group leads to physical encounters and aggressive interactions which can impair animal welfare and performance through their stressful impacts and through injuries arising from fights. Frequent fighting is normally observed 1 to 2 hours following mixing and decreases once a social hierarchy becomes established and piglets become familiar and certain about their social status, a process lasting up to 48 hours (Meese and Ewbank, 1973; Rushen, 1988). The faster a stable social hierarchy is established, the fewer negative impacts there should be on animal welfare.

However, the occurrence of aggression after mixing underlies a variety of individual characteristics and management practices. Fights among pigs with different weights were usually shorter than among pigs of similar weight (Rushen, 1988), probably due to a faster assessment of relative fighting abilities. Individual variation in aggressiveness and prior dominance experience also contribute to the level of aggression observed after mixing (e.g. Hessing *et al.*, 1993; Otten *et al.*, 1999), and the experience of winning or defeat during social encounters is decisive for the individual stress response of immune and endocrine systems (Tuchscherer *et al.*, 1998; Otten *et al.*, 2002). It was shown that, in addition to the mixing with unfamiliar piglets, the new environmental situation causes considerable coping problems for newly weaned piglets (Puppe *et al.*, 1997). However, recognition among fighting piglets appears to be based on learned familiarity and does not involve genetic relatedness (Puppe, 1998; Stookey and Gonyou, 1998). Hence, mutual association over time (e.g. by early mixing) may reduce aggression at weaning. Indeed, it was found that socialising piglets before weaning may increase their social skills and improve social hierarchy formation when pigs are mixed post-weaning (D'Eath, 2005). The age of weaning seems to have no clear-cut effects on the occurrence of aggression post-weaning (Worobec *et al.*, 1999). Allowing litters to mix at young ages, as is the case for free-ranging sows with piglets (outdoors or group lactation indoors), may offer some welfare advantages through pre-exposure of unacquainted pigs. Mixing at this early age causes some aggressive behaviour between unacquainted piglets and some skin damage, but the frequency and intensity of agonistic behaviour generally correspond to low levels. A very important effect of pre-mixing piglets is the decrease in fighting observed after regrouping at weaning and the decrease in aggression-related injuries (Pluske and Williams, 1996a; Weary *et al.*, 1999, 2002).

Environmental enrichment through the provision of substrates and toys can also help to reduce high levels of aggression and manipulations of penmates (O'Connell and Beattie, 1999). The reduction of aggressive behaviour and time spent exploring penmates is accompanied by an increased frequency of substrate-directed behaviours such as rooting (Beattie *et al.*, 2000; Kelly *et al.*, 2000a). In general, the observed manipulations of penmates (nosing, ear- and tail-biting, navel-sucking) under barren conditions are believed to reflect redirected rooting behaviours in the pigs. The reduction in aggressive behaviour in enriched environments may therefore be associated with a reduced need to retaliate against persistent manipulations by penmates (Beattie *et al.*, 2000). The provision of barriers or secure areas, allowing pigs to escape and retreat from aggressive animals, can also be effective in reducing aggression under confined conditions (McGlone and Curtis, 1985; Waran and Broom, 1993). These modifications of management and housing conditions allow the animals to express more of their natural behavioural repertoire and can be an alternative to the drug therapies used to reduce fighting in mixed piglets, which involve the administration of amperozide, tranquillizers or odour maskers (Pluske and Williams, 1996a).

7. Conclusions

Piglets reared in intensive production systems are subject to many constraints which can have negative consequences for their welfare. As shown in this chapter, some of these constraints call for great efforts of adaptation by the animals, and it appears that in many cases the 'Five Freedoms' defined by the FAWC to characterise animal welfare are not completely fulfilled. Freedom from thirst, hunger and malnutrition and, with some exceptions, from pain, injury and disease are largely maintained under commercial production conditions, because of their obvious implications for economic outcomes. Many efforts have been made to reduce high piglet mortality, a major problem for pig breeders, by making modifications to farrowing crates and pens. However, the comfort requirements and behavioural needs of piglets, as well as measures to minimise or prevent fear, stress and suffering, are often not addressed sufficiently, because of the less obvious impact on economic success.

The aim of this chapter was to examine how housing and management can influence the welfare of piglets and to show adequate solutions for their improvement. One important finding is that mimicking some of the conditions of natural weaning (e.g. by pre-mixing and environmental enrichment) can improve the welfare of piglets by reducing behavioural disturbances and aggression, and by allowing the animals to display more of their natural behaviours without negative effects on growth performance. Through this type of approach, piglets can be assisted in make the transition from suckling to weaning with fewer welfare impairments.

For ethical, biological and economical reasons, there is increasing pressure on governments and producers to ensure high welfare and adequate management and housing standards in the context of farm animal production. These aspects have been taken into account partly in recent legislation, e.g. the EU guideline on minimum standards for the protection of pigs (Commission Directive 2002/93/EC). Therefore, basic and applied research on the welfare of domestic piglets is of increasing importance for broadening our knowledge of the animals' specific requirements as well as for the development of production standards. Future research should be based on a combined approach that links the different aspects of welfare related to farmed pigs: scientific measures and their underlying mechanisms reflecting the multidimensional biological nature of animal welfare and the practical problems arising during the rearing of pigs in commercial production.

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Chapter 5. The welfare of growing-finishing pigs

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Abstract

The growing-finishing (G-F) period in commercial swine production represents the phase of production with the longest time and greatest opportunities for improvements in pig performance, health, and welfare. Many factors impact directly or indirectly on the welfare of the G-F pig. Weaning is one of the most traumatic events that piglets experience in most commercial production systems. Factors that contribute to both acute and chronic stressors experienced by the individual piglet are changes in their nutritional supply, changes in their accommodation and mixing of 'foreign' piglets. All can have consequences on the piglets' physical, immunological and psychological status. A plethora of research indicates that early weaning age is strongly related to certain behavioural and physiological problems that some piglets express. Such deviations away from baseline piglet behaviour involve increased expression of vocalisations, belly nosing and aggressive interactions in the first few days following weaning. Applying elements of the pre-weaning environment to the post-weaning environment will ease the stress of weaning. These elements include milk replacer, maternal pheromones and physical environmental enrichments. The most direct influences on pig welfare throughout the grow-finisher stage are the quality and quantity of human interactions, management practices, facility design, genotype, and the health of the pigs. Attention is being focused toward 'alternative' systems (pasture, deep bedded or hoops) and how this filters into premium or niche marketing for producers. Future research areas need to focus on the opportunities for improvement of animal welfare through environmental enrichment, space allowances for the finisher pig and pig handling/people training. In conclusion, the addition of environmental enrichment or the use of alternative production systems for the grow-finisher pig provides an opportunity for premium marketing and enhanced animal welfare of the livestock. The success of these systems will depend on customer and consumer demand for premium products and environmental adaptations of a producer with an appropriate production system.

Keywords: swine, grow, finisher, welfare

1. Introduction

The growing-finishing (G-F) period in commercial swine production represents the phase of production with the longest time and greatest opportunities for improvements in performance, swine health and welfare. The G-F period can be defined as the period from weaning or post-nursery (approximately 4 to 8 weeks after weaning) until pigs reach a market weight. Market weights vary around the world from 80 to 140 kg and thus the G-F period can range from 80 to 180 days. During the G-F period, pigs develop from the post-weaning environment through a long period of growth. Growing-finishing may be in a single barn (called wean to finish or W-F) or they may be in two barns: a nursery and then a G-F barn. Older systems used three barns: a nursery, growing and finishing barn. The combination first of G-F and later of nursery-growing-finishing leads to the newer W-F production system. Many factors impact directly or indirectly on the welfare of the G-F pig. The most direct influences on pig welfare are the quality and quantity of human interactions, management practices, facility design, genotype and the health of the pigs. The influences of these direct factors will be discussed during the time line from weaning to marketing of pigs.

2. Welfare of the recently weaned and nursery pig

2.1. Weaning – acute and chronic stressors

Weaning is one of the most traumatic events that piglets are exposed to regardless of their age. Factors that contribute to both acute and chronic stressors experienced by the individual piglet are changes in their nutritional supply, their accommodation (physical movement from the lactation facility to a nursery unit) and mixing of 'foreign' piglets, which can all have consequences on the piglets physical (Leibbrandt *et al.*, 1975; Stanton and Mueller, 1976) immunological (Blecha *et al.*, 1985) and psychological status (McGlone and Curtis, 1985; Pajor *et al.*, 1991).

2.2. Weaning age: U.S. practices and E.U. legislation

In North America, weaning age on commercial pig farms has been decreasing steadily, with the majority of piglets now weaned between 21 and 34 days of age (Weary and Fraser, 1997), but on larger farms the weaning age is often between 17 to 20 days of age (McGlone and Johnson, 2003). In the past decade, segregated- and medicated-early-weaning (SEW and MEW respectively) practices have been used by swine producers to optimise the health of their piglets (Alexander *et al.*, 1980) to improve feed efficiency and growth rate and therefore to improve economic efficiency (Hohenshell *et al.*, 2000; McGlone and Johnson, 2003). The primary economic advantage for early weaning is for the sow herd. The sow herd can turn over more pigs per sow per year (PPSPY) with an average 17 days weaning window compared with 28 days weaning.

However, there have been reported disadvantages of early weaning management practices which include inconsistent growth performance throughout the finisher stage (Wiseman *et al.*, 1995), decreased post weaning gain (Leibbrandt *et al.*, 1975) and abnormal feed intake that may affect metabolism (Pittaway and Brown, 1974). Dritz *et al.* (1996) disagreed with Leibbrandt *et al.* (1975) in that SEW piglets (7 to 10 days of age at weaning) actually gained faster (23.7 kg) after weaning compared to their control (12.5 kg) counterparts (weaned at 14 to 17 days of age). Orgeur *et al.* (2001) found a growth check at weaning and in addition they found detrimental physiological and behavioural alterations associated with early weaning. One group was weaned at approximately 6 days of age (early weaned; EW) and the second group was weaned at approximately 28 days of age (Control; CONT). EW piglets walked, vocalised, belly nosed and engaged in more aggressive interactions than CONT piglets. EW pigs also displayed a more marked growth check (6.8 vs. 8.15 kg) after weaning than CONT piglets until 28 days of age. In EW piglets at 36 days of age there was a higher density of T- (12.9 ± 2.8 vs. 6.3 ± 1.7) and B- (8.3 ± 0.3 vs. 5.0 vs. 0.3) lymphocytes in the gut epithelium and lamina propria in relation to the size of the lymphoid follicles of Peyer's patches. However, even with some of these differences seen in early weaned groups Hohenshell *et al.* (2000) concluded that most behaviour, performance and physiological differences are seen in the period immediately after weaning but have disappeared by the time of processing.

In the European Union (EU) there are minimum welfare standards already in place to offer protection to swine on farm (EU Directive 91/630/EEC as amended by Directive 2001/88/EC and Directive 2001/93/EC). These directives note that '*Piglets should not be weaned from the sow at less than three weeks of age unless the welfare of the sow or piglets would be adversely affected*'. The EU 91/630/EEC directive has now been amended so that any new or re-built facility as of January 1, 2003 and all buildings as of January 1, 2013 will follow the following language; '*No piglets shall be weaned from the sow at less that 28 days of age unless the welfare or health of the dam or the piglet would otherwise be adversely affected. However piglets may be weaned up to seven days earlier if they are moved into specialised housings which are empted and thoroughly cleaned and disinfected before the introduction of a new group and which are separated from housings where sows are kept, in order to minimise the transmission of diseases to the piglets*' (DEFRA, 2004).

2.3. Weaning age: effects on recently weaned and nursery pigs

There is a plethora of research on the effects of weaning age on piglet behaviour, physiology and overall performance throughout the nursery stage. Weary and Fraser (1997) weaned piglets at 3, 4 and 5 weeks respectively and reported that younger piglets vocalised more at weaning (average of 3.6 calls/min) but the frequency for all groups fell by day four post weaning (1.6 calls/min). In contrast with this reduction in vocalisation, piglets can increase their performance of certain 'undesirable behaviours', such as belly nosing; which has been hypothesised to be displaced nursing behaviour due to the piglets immaturity at weaning (Metz and Gonyou, 1990; Dybkjaer, 1992), tail chewing (Fraser, 1987; Broom, 1993; Worobec *et al.*, 1999), ear sucking (Fraser, 1978; Blackshaw, 1981), flank biting (Gonyou and Whittington, 1997) and escape behaviours (Worobec *et al.*, 1999).

Worobec *et al.* (1999) compared three weaning ages (7, 14 and 28 days) on piglet feeding behaviour and reported that the speed at which piglets begin to feed on solid food is an important indicator of how well they are adapting to weaning. Piglets weaned at 7 days spent less than 1% of their time at the feeder in the first 2 days following weaning, compared to 3% for piglets weaned at 14 days and 5% for those weaned at 28 days. Leibbrandt *et al.* (1975) weaned piglets at 2, 3 or 4 weeks of age respectively. Body weight before weaning for the three groups were similar, all groups experienced a 'one week lag' but overall weight gains for piglets weaned at 4 weeks of age were higher (564.1 g/d) compared to those weaned at 2 weeks of age (359.4 g/d). Six weeks after weaning, piglet body weights for all three groups were similar.

Physiological differences have also been observed among piglets weaned at different ages. For example higher plasma cortisol concentrations were found in piglets weaned at 3 weeks compared to those weaned at 8 weeks (Worsaae and Smidt, 1980) and an early weaning age was found to decrease cellular immune reactivity and these changes were suspected to affect disease susceptibility (Blecha and Pollmann, 1983). Carroll *et al.* (1998) also noted changes in immune function of piglets weaned at either 2 or 3 weeks of age. Serum insulin-like growth factors (IGF-1 and IGF-2), and average daily gain were reduced in both groups as a result of weaning. Earlier weaning resulted in a greater reduction in growth rate and serum IGF-2 values. Serum thyroxine (T_4) and triiodothyronine (T_3) levels were unaltered by weaning but declined in both groups after piglets went through a dietary change.

2.4. The nursery environment

2.4.1. Alterations to the olfactory environment

The olfactory environment post-weaning is foreign and contributes to the stressfulness of the new environment. The strong effect that maternal pheromones have on piglet-sow interactions and the effect that maternal pheromones play in regulating nursing piglet behaviours has been investigated by Morrow-Tesch and McGlone (1990). They found that piglets can detect maternal pheromones as early as 12 hours of age. Pageat (2001) isolated skin secretions from sows and then developed a fatty acid mixture that is similar in composition to odourous sow skin secretions. This formulation was thought to contain the essential elements of a possible maternal pheromone. Pageat and Teissier (1998) reported preliminary results suggesting piglet aggressive biting was reduced by use of this synthetic pheromone when piglets were mixed after weaning. In a more comprehensive study, McGlone and Anderson (2002) exposed weanling piglets to maternal pheromone or a placebo control and measured post-weaning behaviour and performance. In this study, the maternal pheromone (Suilence, Ceva Sante Animale, Libourne, France) was applied to the feeder or the snout of weaned piglets. Piglet post-weaning feeding behaviour was increased and agonistic behaviours were decreased. Weight gain was also stimulated and the piglets were about 1 kg heavier four weeks after weaning when exposed to the maternal pheromone at weaning.

2.4.2. Mixing of unfamiliar piglets

Mixing unfamiliar piglets is a common practice at weaning. While outdoor pigs show fewer aggressive interactions during mixing (Sarignac *et al.*, 1997), conventional indoor-farrowed piglets show considerable aggressive interactions after weaning and mixing (McGlone and Curtis, 1985; Rushen, 1987). Klont *et al.* (2001) found that pigs reared in enriched environments fight less as well. Piglet aggression was observed during paired social encounters between piglets as young as 5 days of age (Pitts *et al.*, 2000). Aggressive interactions may result in wounding (McGlone and Curtis, 1985) or leg injuries (Hessing and Tielen, 1994). Hohenshell *et al.* (2000), indicated that, although some behavioural differences were evident in early weaned (10 days) piglets in regards to more time play fighting and manipulating conspecifics than later weaned piglets (30 days), overall most differences found between the two groups were evident after weaning but disappeared before processing. Agonistic behaviours can be reduced by use of boar odour among prepubertal piglets. McGlone *et al.* (1987) showed that the odour of dominant pigs reduced agonistic behaviours in other weaned piglets. McGlone and Morrow (1988) applied even very low concentrations of 5-alpha-androstenone to piglets and reduced post-weaning agonistic behaviours by over 80%. However, this compound was never commercialised. The maternal pheromone

(Morrow-Tesch and McGlone 1990; Pageat, 2001) shown to reduce fighting in the weaned piglet (McGlone and Anderson, 2002), however, is a natural product and is commercially available. The maternal pheromone is a natural odour that replaces a missing maternal odour when applied in the post-weaning environment. The boar odour would represent a supranormal stimuli for weaned piglets. Use of the maternal pheromone among newly weaned pigs stimulated feeding behaviour and post-weaning weight gain (McGlone and Anderson, 2002).

2.4.3. How the farrowing environment may affect adaptation by the piglet to weaning

As introduced in Chapter 4 on the care and well-being of the farrowing sow and her litter, rearing conditions for piglets may have long-term effects on social relationships that piglets are able to form (Newberry and Wood-Gush, 1988). For example it has been reported that indoor-born and raised piglets display greater activity at the udder and suckle more compared to outdoor-born piglets (Sarignac *et al.,* 1997). From weaning to day one post weaning, Webster and Dawkins (2000) and Cox and Cooper (2001) observed that outdoor-bred piglets spent more time feeding than their indoor counterparts. Indoor-born piglets were more likely to engage in agonistic encounters compared to piglets born outdoors (Sarignac *et al.,* 1997; Cox and Cooper, 2001) but nose contact, belly nosing and tail biting were not different (Cox and Cooper, 2001). These differences in agonistic behaviours could be related to social experiences. Outdoor piglets can interact with alien piglets of different ages and sizes and the quality of the interaction may be different, with outdoor piglets having more space to resolve conflicts. Consequently following weaning, the outdoor-born piglet may be able to establish hierarchies without resorting to aggressive encounters.

2.4.4. Environmental enrichment and the occurrence of play behaviour

Numerous authors have investigated the relationship between 'toys' in an environment (providing environmental enrichment) that is lacking in stimulation for recently weaned piglets and how this affects behaviour and performance. One behaviour which has been debated to be a sensitive indicator for assessing the well-being of young piglets (Buchenauer, 1981) is play behaviour, but to date this behaviour has been inadequately described for piglets (Blackshaw *et al.*, 1997a). Worsaae and Schmidt (1980) reported a negative correlation between plasma cortisol level and playful behaviour fighting and running in piglets; Lawrence (1987) suggested that farming systems could ensure good well-being standards by allowing or enabling play behaviours. The definitions of play differs between researchers, but most agree that it describes piglets engaged in the following behaviours: mock combat, hopping, scampering, pivoting, tossing head, shaking and or carrying an object (Worsaae and Schmidt, 1980; Newberry and Wood-Gush, 1988).

Newberry and Wood-Gush (1988) studied piglet playful behaviour from birth to 14 weeks for piglets kept under semi-natural conditions and overall piglets engaged in more play behaviour between 2 and 6 weeks of age. Grandin and Curtis (1984a,b) reported that pigs which were exposed to a more complex environment would approach strange people and unfamiliar novel objects more quickly than pigs raised in simple pen environment. In addition these authors also noted that if toys were not changed often the pigs decreased the amount of time spent interacting with them and that the pigs on study did have 'preferred toys'. Schaefer *et al.* (1990) conducted two experiments to determine the effects of environmental enrichment on the incidence of aggression in newly weaned piglets. Six-week old gilts were divided into two treatments (1) a suspended car tire and (2) nothing (CONT). Pigs that had access to the tire displayed fewer (948 vs. 1107 acts of aggression/24 hour period) compared to their CONT counterparts, with the most notable change in behaviour being the number of 'head knocks' a pig received in the tire treatment (64/24 hour period) compared to their CONT counterparts. In experiment 2, barrows and gilts were used (28 days of age) and were divided into three treatments (1) CONT, (2) Pacifier (sugar-mineral block suspended in a metal basket) and (3) a Teeter-totter (metal bar with rubber belts on the end). Similar findings were reported again in that pigs provided some form of enrichment again engaged in fewer aggressive displays (46 (CONT), vs. 22 (Teeter-Totter) vs. 30 (Pacifier)/pig/24 hour period) respectively. In agreement to the previous findings, Blackshaw *et al.* (1997b) provided fixed or free toys to recently weaned pigs and assessed if there were behavioural and performance differences and also if hierarchy of pigs affected the time involved to approach and interact with a novel environment. Blackshaw *et al.* (1997b) did not correlate hierarchy and time taken to touch a toy nor did they report any growth benefits by having a toy in the pen. However, over 75% of the weaned piglets in all treatment groups investigated the toy by touch within 5 minutes of the toy being placed in the pen and observed fewer aggressive interactions within the pens were lower which may result in improved piglet welfare at the time of weaning.

2.4.5. Nutritional disruption and change from the lactation to nursery environment

Prior to weaning, piglets have access to hourly meals of high quality readily digestible ingredients consisting of simple carbohydrates, proteins and fats provided by the sow's milk (Pond and Maner, 1984). At the time of weaning, piglets are faced with a radically different nutritional source – a pelleted ration with liquid being restricted to water. This dietary alteration effects gut local immune status and gut microflora (Hampson *et al.*, 1985; Barnett *et al.*, 1989) and digestive enzyme activity (Sloat *et al.,* 1985). Combining this dietary change with an early weaning regime, problematic effects of delayed feeding, increased behavioural problems and excessive drinking has been reported. Holub (1991) and Gonyou *et al.* (1998) observed that early weaned piglets spend more time at nipple drinkers and use more water than those weaned at a later age. Torrey and Widowski (2004) suggested that excessive drinking behaviours witnessed immediately after weaning may be the result of an interaction among the motivational systems for ingestive behaviours that interfere with the pig's ability to adapt to weaning. Torrey and Widowski (2004) hypothesised that stimuli in the piglets' nursery environment may also elicit sucking and therefore excessive drinking behaviour. Two waterer types (nipple versus bowl drinkers) were compared on the propensity of drinking behaviours and the development of oral-nasal behavioural patterns at the time of weaning (at 15 days). Piglets with drinker bowls had a higher feed intake during the first 2 days after weaning (61.7 ± 6.4 vs. 44.4 ± 5.2 grams/pig/day) and engaged in less drinking behaviour (4.7 ± 0.42 vs. 2.54 ± 0.51 minutes/pig) than piglets with nipple drinkers.

2.4.6. Undesirable behavioural deviations in the recently weaned piglet

Behavioural problems noted with early weaning piglets can include flank or belly nosing, also referred to as navel sucking, flank rubbing and persistent inguinal nose thrusting. On occasion, flank rubbing has resulted in severe necrosis of skin with ulcer formation at the site of the attack but most injuries appear as hyperemia (excess of blood) and edema (pathological accumulation of fluid in tissue spaces) of the skin with loss of hair and superficial erosion (Straw and Bartlett, 2001). Belly nosing has been reported to occur several days after weaning with peak activity 2 to 4 weeks later (Straw and Bartlett, 2001). Multiple researchers have noted that the overall time that piglets engage in belly nosing rarely exceeds 2% of their total time (Fraser, 1978; Dybkjaer, 1992; Van Putten and Dammers, 1976). Several theories have been proposed to explain why 'nosing' develops. It may be due to udder seeking or exploration through rooting behaviours, it may represent a coping mechanism as the piglets has been removed from a familiar and 'safe' environment with their dam to an unfamiliar pen, full of 'alien' piglets (Straw and Bartlett, 2001). Torrey and Widowski (2004) noted that pigs with bowl drinkers engaged in less belly nosing (1.12 vs. 1.98%) than for those pigs that had access to nipple drinkers. The authors concluded that because drinker type and the motor patterns that it accommodates affect belly nosing, it may be that the internal stimuli associated with nursing such as the actual sucking, play a large role in the development of abnormal oral-nasal behaviours.

It is unclear if belly nosing impacts piglet performance. Gonyou *et al.* (1998) reported no effect on growth while Fraser (1978) and Dybkjaer (1992) reported that these piglets grew more slowly. Straw and Bartlett (2001) did not find any gender differences (51.2% barrows vs. 48.4% gilts) for the propensity of a piglet to become a 'noser' (a piglet likely to engage in belly nosing activities) nor was there a detrimental effect on growth rate.

3. Main grow-finish period

3.1. Human-pig interactions and the need for on-farm training

Growing-finishing pigs interact with their environment and with people during the G-F period. Both the environment (discussed below) and the people can have significant effects on the pigs' welfare and productivity. Human interactions can take many forms during the G-F period. Pigs may have no human contact, or neutral, positive or negative human contact.

Pigs respond to humans differently depending on their previous experiences. Naïve pigs will be more averse to humans that are standing, with gloved hand and moving towards the pig while humans are less aversive to pigs when people are squatting, using a non-gloved hand and allowing the pigs to initiate the interaction (Hemsworth *et al.,* 1986a). Pigs may have a 'sensitive period' early in life (for example, during the early G-F period or during suckling). Positive human interaction during early life improves pig handling later in life (Hemsworth *et al.,* 1986b).

Negative/aversive human contact includes being abusive to pigs intentionally or non-intentionally to such a degree that pigs are fearful of human interaction. If pigs expect a painful experience when they interact with people, then they will naturally become fearful of people. One problem with assessing pig fearfulness is that pigs with no human contact are also fearful of people. Thus fearful pigs are caused by one of two often indistinguishable causes: lack of human contact or negative human interactions. Terlouw and Porcher (2005) found that when pigs are in presence of a human they want to touch or interact with the human, even if this contact is consistently refused. Hill *et al.* (1998) demonstrated the 'fearful' pig behaviour among pigs that were raised with virtually no human contact. This pig behaviour – the ultimate naïve pig – is not the result of physical abuse. Neglected pigs are fearful of people and new experiences.

Repeated positive interactions with pigs will make them easier to handle up to a point. Handling/interacting with pigs twice per week every other week resulted in pigs being easier to handle at truck loading (72.7 ± 6 vs. 144.1 ± 13.2 vs. 169.6 ± 13.2 seconds) compared to their handling and CONT counterparts. However, there were no differences in pig exploration behaviour at the packing plant between these the treatment groups (35.5 ± 6 vs. 38.9 ± 3.1 vs. 40 ± 3.7 seconds) respectively (Geverink *et al.,* 1998). However, if the pigs had positive human contact every day, they were more difficult to move than pigs with positive handling only once per week, although the total time to move pigs through a novel course was not different among the treatments (Hill *et al.,* 1998). If pigs experience too much positive human interaction, then they follow people rather than being driven from behind. A pig turning around while being moved forward in aisles and chutes is not positive, especially if a large number of pigs are to be moved.

Any time when pigs move counter to the desired direction and speed of flow or balk at an object or person, there is a welfare concern. The U.S. swine industry has defined the differences between ill, severely injured and fatigued pigs. The definition is as follows '*The position of the National Pork Board is that any pig that is unable to walk, ill or significantly injured, should not be transported to market channels. Where the likelihood of recovery is low, even with treatment, the pig should be euthanised. Any pig that becomes fatigued should be moved to a resting area in an appropriate manner. A fatigued pig is defined as having temporarily lost the ability to walk but has a reasonable expectation to recover full locomotion with rest. A resting area enables recovery by minimising competition for feed and water and provides opportunity for monitoring*' (NPB, 2004a).

Professional assistance should be sought from qualified individuals (Pork Quality Assurance Program Plus (PQA plus) Advisors, veterinarians or animal scientists), who understand swine production and welfare, to determine protocols for handling, movement or euthanasia of pigs. Pigs that are ill, injured or fatigued must be handled in a humane manner. Proper handling and movement of ill, injured or fatigued animals should be included in the general handling and movement policy of the production, transporting and packing operation. This policy should include a framework for ethical decision making and provide adequate training, equipment and supervisory resources for all caretakers working directly with pigs. Prevention, preparation and prompt action are keys to proper pig handling. Producers should seek to prevent illness and injuries by feeding nutritionally sound diets, maintaining effective health programs, good facilities, proper handling, and selecting genetically and structurally sound breeding stock. Causation of fatigued pigs is not well understood. Good production practices along with proper handling and movement will reduce the incidence of fatigued pigs. Handling methods for moving ill, injured or fatigued pigs should include appropriate equipment for the size, age and condition of the pig. When pigs become too large to be carried in a safe manner, proper tools for moving these animals should be used, including sleds, hand carts and mechanised equipment (NPB, 2004a).

The need for an on-farm and continuing educational program is critical to improve swine welfare. Coleman *et al.* (2000) demonstrated this when pig caretakers were firstly given an attitude and behavioural survey and then were randomly allocated to a control group (where no training was received) or a trained group (where after the survey these caretakers received detailed training to modify their attitudes and behaviour towards pigs). After the intervention had occurred the caretakers were given the same survey again. Interestingly the caretakers attitudes towards pigs improved, swine withdrawal behaviour also reduced for those caretakers who had received training. Six months after the survey the retention rate for employees that had participated in the training program was 61% compared to the rate for those which had not participated (47%).

An essential component to handling swine and the experience (positive, negative or neutral) that a pig will receive is based on the attitudes and beliefs that an individual caretaker holds about pigs. Coleman *et al.* (1998) reported that attitude variables were the most consistent predictors of behaviour, and that other, job-related variables correlated with attitudes but did not contribute greatly to predicting behaviour. In some follow up work, Coleman *et al.* (2003) reported that positive attitudes both general and behavioural were associated with use of an electric prod with the power turned off, while negative attitudes were associated with the use of the prod with the power turned on. Pigs that experience negative/aversive human interactions grew slower than pigs that experienced minimal or positive human interactions (Gonyou *et al.*, 1986). But pigs that experience frequent positive human interactions did not grow any faster than pigs with minimal human contact (Gonyou *et al.*, 1986; Hill *et al.*, 1998).

3.2. Pig moving devices

Pigs must be moved in familiar and novel environments during and at the end of the G-F period. Pigs that move counter to the desired flow cause a welfare concern because the human caretaker is more likely to use a moving device to touch a pig. Any need for moving devices increases the risk that negative pig contact will occur. Thus, the best pig welfare will be where pigs flow through aisles and chutes without the need for moving devices.

Certain moving devices have been used for a long time and some are newer. The traditional and perhaps the most time-tested moving device is the board. A moving or sorting board is a rectangle or square with holes for hand grips that measure a little less wide than the aisles in a pig barn. The board is placed between the person and the pigs with the idea that pigs are to move forward. Pigs that move back or turn around are at a risk of being handled in a rough manner. The sort board also reduces the risk of the pig handler's feet and knees from being stepped on or injured.

Some people move pigs with an electric prod or goad. This is a device that delivers a low-amperage, high voltage electric shock to the pig's skin (shoulder, back, ham or legs). The electric prod provides for the ability to reach pigs that are far (about 1 m) from the point in which the pig handler is standing. Because the electric prod delivers a painful experience, it is associated with reduced pig welfare. Usually the electric prod is used when the facilities are poor or the pig handlers are not well trained. Some farms and processing plants in the USA and in Europe have banned the use of electric prods in some or all of their stages of pig production, however their use remains widespread. The National Pork Boards policy on the use of electric prods is '*The use of electric prods is a stressful event and should be avoided or absolutely minimised. Pigs should never be prodded in sensitive areas such as the eyes, nose, anus, testicles, etc. If regular use of an electric prod is needed, reevaluate your handling procedures and facilities with your Educator. There may be ways that you can increase your pigs' familiarity with people*' (NPB, 2003a).

Newer devices include the rattle paddle, the flag and the cape. A rattle paddle has a light-weight plastic handle with a wide plastic paddle on the end and the paddle contains small plastic beads that make noise when moved. The flag has the same sort of handle as the rattle paddle, but with a light-weight plastic flag on the end. The flag is waved in front of the pigs to get the pig's attention, induce fear and (or) startle the pig into movement. The rattle paddle and flag provide the same reach as the electric prod. The cape is a newer device that is composed of light-weight plastic material that is folded in a tri-fold that can be opened wide to cover a large area.

A recent study compared the efficacy of pig moving devices. McGlone *et al.* (2004) in a series of experiments moved groups of naïve pigs out of a pen, down and aisle and through a course (simulating departure, but not actually loading on a truck). The authors found that the color of the paddle (red, blue, green) did not change the moving time or pig responses. In addition, the authors found that touching the pig on the ham or back was more effective than touching the pig on the shoulder or sides when the objective was to move pigs forward. The pig's reaction to the electric prod and the paddle were interesting. Pigs turned back towards the investigator about one-third of the time when the electric prod and paddle were used. While 0% of pigs jumped with the use of the paddle, 15% of the pigs touched with the electric prod jumped. More than 50% of the pigs vocalised when either the paddle or prod was used compared with only 4% of the pigs when moved with the board. These results indicate that the electric prod and paddle may be annoying in a similar manner and the board may be less annoying to the pig and the board is more likely to get the pigs moving in the desired direction (forward). Apart from the pig's reaction, an important question for the pig handler is how much time is required to move pigs from one place to another and do the moving devices differ in the time to complete a task. The time required for pigs to move through the course was evaluated for 99 pigs using the electric prod, board or paddle. Use of the electric prod or paddle resulted in over 50% greater time required to move pigs than when the board was used.

The flag or paddle can replace the electric prod. The cape can be used as a very wide board in a large or wide area (such as in a pen where pigs are to be removed). The board is still the best device to be used in a cramped space where pig backward movement is to be prevented. One model has a team of people that empties G-F pens for transport using a cape in the pen, and a board and flag (or rattle paddle) when pigs are in the aisle.

3.3. Genetics

Pigs of different genetic types may respond differently to housing systems or degree of handling. However, generalisations about the response of certain genotypes to certain grower environments can not be made. Guy *et al.* (2002) compared two crossbred genetic lines in outdoor paddocks, straw yards or fully-slatted pens. Hill *et al.* (1998) studied two genetic lines exposed to five levels of handling from zero handling to positive frequent handling. In both studies, the authors did not find many interactions among environments and genotypes. The environments had a large effect and the genotypes had effects, but the interactions were not significant. Calm genotypes are calm in different environments. More active genotypes are active in each environment. This is not to say that interactions are not possible – but to date they have not been documented. An important conclusion from these two studies is that each production system and each genotype has a certain behavioural type that requires certain levels and types of handling.

4. Housing and environmental effects on welfare and meat quality of the G-F pig

In recent years, many challenges have faced the pork producer. Examples of these challenges may include a high cost of construction for modern, indoor swine facilities, challenges of utilising liquid manure from an environmental standpoint, monitoring and dealing with ammonia and other airborne gases (NPB, 2003a,b), and space allowances given for the G-F pig (Gonyou *et al.*, 2004, 2006). Current space allowance guidelines for the U.S. swine industry can be found in Tables 1 – 3 (NPB, 2003b).

There are many reasons to consider alternative finishing systems such as outdoors or deep-bedded swine finishing systems. Some of these include animal welfare issues. For example, there have been reports of greater incidence of foot and leg problems associated with pigs housed on concrete flooring compared to alternative systems (Fritschen and Mueling, 1984; Gentry *et al.*, 2002a). Furthermore, there has been increasing opportunities for producers to market pigs finished under alternative systems through niche markets (Berkshire Meats, 2005; NPB, 2004b; Niman, 2005). Often, pigs are placed in alternative systems at the time of weaning, and may remain in

Table 1. Floor area recommended for growing swine in totally enclosed housing[a,b]

Stage of production		Measure[c]	
lb	kg	sq ft / pig	m^2 / pig
12 – 30	5.4 – 13.5	1.7 – 2.5	0.15 – 0.23
30 – 60	13.5 – 27	3 – 4	0.27 – 0.36
60 – 100	27 – 45	5	0.45
100 – 150	45 – 68	6	0.54
150 – market	68 – market	8[d]	0.72

[a]Adapted from MWPS (1983): Chapters 1, 2 and 3; Fritschen and Muehling (1987): Chapters 1, 2 and 3.
[b]Close observation and professional judgment in modern facilities may allow higher stocking densities without interfering with the pigs' welfare. Production practices, such as group size, ventilation equipment and rate, and type of floors (partial versus total slats), have an effect on proper stocking densities. Research is ongoing to study space requirements for different production systems.
[c]Group area allowances for growing pigs.
[d]Space requirement per pig decreases as group size increases (Chapter 1, McGlone and Newby, 1994).

Table 2. Space recommendations for growing – finishing pigs in buildings other than totally enclosed housing[a]

Housing with outside apron					
Inside		Outside		Bedding system	
sq ft / pig	m^2 / pig	sq ft / pig	m^2 / pig	sq ft / pig	m^2 / pig
6	0.54	6	0.54	10.5 – 12	0.95 – 1.1

[a]Adapted from Fritschen and Muehling (1987): Chapters 1, 2 and 3.

Table 3. Space and shade or shelter recommendations for growing – finishing pigs on pasture[a,b]

Pasture		Shade or shelter	
Acre	Hectare	Pigs up to 100 lbs (≤ 45 kg)	Pigs over 100 lbs (> 45 kg)
50 to 100 pigs	124 to 247 pigs	4 sq ft / pig; 0.36 m^2 / pig	6 sq ft / pig; 0.54 m^2 / pig

[a]Adapted from MWPS (1983): Chapters 1, 2 and 3; Fritschen and Muehling (1987): Chapters 1, 2 and 3.
[b]Space needs for pigs in outside dirt lots may be less than for pigs on pasture.

the same environment until processing. This reduces the stressors that are commonly associated with mixing unfamiliar pigs, handling and moving.

The practical application and use of environmental enrichment, deep-bedded systems, and outdoor finishing systems for swine will be further examined. In some cases, pigs that have poor meat quality are expected to have experienced stress either during handling or during the G-F period. Alternatively, pigs with poor meat quality may have been previously sensitised to have an adverse effect of transport and pre-slaughter handling on pork quality. Thus, pork quality in many, but not all cases can be linked to the stressfulness of the G-F period. Other non-growing-finishing period effects include transportation, pre-slaughter handling and genetic influences. These latter effects may interact with the growing-finishing production system to impact pork quality and pig welfare.

4.1. Environmental enrichment

Environmental enrichment (presence of bedding, toys, human interaction, etc.) may be beneficial to G-F pigs by allowing them to express their natural behaviours and reduce stress levels of pigs in confinement. Studies on environmental enrichment for pigs have shown that earth-like material is an effective enriching agent (Beattie *et al.*, 1998). In previous studies, environmental enrichment was only incorporated after weaning (Warriss *et al.*, 1983; Pearce and Paterson, 1993), but Hessing *et al.* (1993) found that characteristics such as stress responsiveness (that can affect pig performance and meat quality) are established earlier in life. Beattie *et al.* (2000a) reported that pigs finished in enriched environments (3.5 m^2/pig, solid flooring with straw bedding) had greater growth rates during the last stage of finishing (15 to 21 weeks) compared with pigs finished in a barren environment (0.76 m^2/pig, concrete slats).

Beattie *et al.* (1995) also showed that enriching the environment by adding straw or peat to the pens and increasing space allowances by four times, reduced tail biting and persistent nosing of penmates. Other researchers have determined that decreasing space allowance increased frequency of agonistic behaviour (Ewbank and Bryant, 1972; Meunier-Salaun *et al.,* 1987) and tail biting (Jensen, 1971; Randolph *et al.,* 1981). Beattie *et al.* (1996) determined that environmental enrichment (presence of peat and straw in the pen) played a greater role in determining pig behaviour than floor space allowance. These researchers also determined that space allowances greater than 1.1 m^2/pig had no effect on performance parameters such as weight gain or feed efficiency. Hill *et al.* (1998) evaluated environmental enrichment for pigs in nursery and finishing phases and found no improvement in pig performance, ease of handling or meat quality with the use of environmental enrichment (toy chains and hoses, human contact). Others determined that enriching agents (peat or straw) resulted in less aggressive behaviour and less harmful social behaviour of pigs when compared to pigs in a barren environment (Beattie *et al.,* 2000b). Pigs reared in the barren environment had a lower level of environmental exploration that was accompanied by higher levels of sitting, standing or lying inactive (Beattie *et al.,* 2000b). Researchers have determined that growing pigs prefer to lie on straw under cool temperatures but prefer bare floors at higher temperatures (Fraser, 1985). Therefore, the potential benefit of bedding for finisher pigs would be for environmental enrichment. Fraser *et al.* (1991) confirmed earlier work by Kelley *et al.* (1980) that the presence of straw in pens for G-F pigs reduced rooting and chewing of penmates. The straw functioned in providing a stimulus and outlet for rooting and chewing, which resulted in a reduction of these behaviours directed at penmates.

4.2. Deep bedded systems

Hoop-style pig finishing houses have become popular on some farms in the United States and in other parts of the world. A hoop structure usually consists of 1.2 m-high wooden sidewalls fitted with steel tubular arches covered by an opaque, UV-resistant polypropylene tarp. Hoop structures are naturally ventilated. Most of the floor area inside the hoop building is bedded with cornstalks or other crop residues. The remainder of the floor area is a concrete slab for feeders and waterers. The group size for hoop structures ranges from 150 to over 250 head with a space allowance of approximately 1.1 m^2 per pig.

Some of the major differences between hoop-style and conventional finishing buildings are the use of bedding, manure management, natural ventilation, larger group sizes, more environmental variation, and usually a lower initial investment. Some advantages may exist for the animal if finished on bedding. Pigs on bedding show less tail biting, have fewer foot pad lesions (Gentry *et al.,* 2002a), have fewer leg problems, and tend to have fewer respiratory problems than pigs on slatted flooring (McGlone, 1999). Lay and Haussmann (2000) determined that pigs finished in hoops performed fewer abnormal behaviours, had a greater rate of play behaviour and fewer leg injuries than pigs finished in a non-bedded confinement system. Pigs in hoops generally have more space and have been observed to engage in a richer behavioural repertoire. Pigs are able to choose a microclimate within the building and it is easier for them to escape from aggressive interactions in a deep-bedded system. In addition, some detrimental behaviours can be reduced by increasing space allowance. However, tail biting and aggressive interactions can still occur in deep-bedded systems (although at a lower level than conventional indoor systems on slats). To date there has been little scientific research done to consider some of the challenges to the pasture system and how to implement good production practices to manage these concerns. Some challenges could be, but are not limited to identification and treatment of sick and injured pigs, handling and moment of pigs in extensive environments and sorting pigs at the time of market to meet niche marketing specifications and/or packer grids.

4.3. Outdoor production systems

Intensive outdoor pig production systems have been considered in recent years in several parts of the world (PII, 2005). Outdoor systems usually consist of a large paddock and shelter for the pigs. Climatic conditions and available land are two limiting factors to consider when producing pigs outdoors. These alternatives to traditional slatted-floor indoor systems may become more common as environmental or animal welfare regulations become more intense (although alternative systems have their own challenges). Outdoor pig production systems have lower capital costs, which can vary from 40 to 70% of the cost for conventional indoor systems (Thornton, 1988) but currently, less than 6% of the pigs finished in the United States are housed on pasture or dirt pens (USDA, 2001). Many studies of housing system effects on pig performance and pork quality have yielded widely differing conclusions. Some researchers have determined that pigs finished outdoors had less backfat than pigs finished indoors (Warriss *et al.*, 1983; Enfält *et al.*, 1997; Sather *et al.*, 1997).

Just because pigs are kept outdoors does not mean their welfare is automatically better than indoor-kept pigs. Outdoor environments can be harsh in temperature extremes or in sanitation (varying from very clean to very dirty). Even outdoor, organic pigs can have potential welfare problems (Barton-Gade, 2002). From a pig welfare-point of view, conditions should be such that each production system attempts to improve pig welfare within the constraints of the system. Calls for audits to assure good pig welfare and continuous improvement in pig welfare in each system have been made (Barton-Gade, 2002; McGlone, 2004). Furthermore, it was suggested that improvements in animal welfare be made in concert with consideration of other society issues such as environmental protection and food safety (McGlone, 2001).

4.4. Pork quality

Research trials investigating the effects of environmental enrichment on pork quality measures have been published with some conflicting results. Gentry *et al.* (2002b) determined that finishing pigs outdoors on alfalfa pasture resulted in improvements in pork color and tenderness. Beattie *et al.* (2000a) determined that pigs finished on straw bedding in an enriched environment had greater levels of backfat and heavier carcass weights than pigs finished in a barren environment. Others have found that environmental enrichment resulted in no improvement in productivity (Pearce and Paterson, 1993; Blackshaw *et al.,* 1997b). The nature of the enrichment and the length of exposure to the enrichment may explain the conflicting findings reported thus far.

Research comparing growth and meat quality characteristics of pigs finished in hoops and other deep-bedded systems has been limited. Gentry *et al.* (2002a) determined that pigs finished on bedding had heavier carcass weights, more backfat at the last rib measurement, and no differences in loin quality measures when compared to pigs finished on slatted flooring. Honeyman *et al.* (2001) determined that pigs finished in hoops ate 4.9% more feed, grew 1.7% faster, required 3.4% more feed per unit of live weight, had 4.9% thicker backfat measurements, and had a 4.8% smaller loin-eye area. Perhaps pigs finished in hoops will need to be fed diets somewhat differently than the diets fed to confinement pigs to optimise lean growth. Another long-term study comparing bedded hoop structures (corn stalks) versus confinement in Iowa was conducted (Honeyman and Harmon, 2003). They reported that pigs finished in hoops during the summer grew faster than pigs in confinement, but during the winter, growth rates were similar between the two finishing systems. Also, the hoop-fed pigs had more backfat than the confinement-fed pigs. Overall results indicate that pigs finished in hoops ate more feed, grew faster and required more feed per unit of live weight gain than confinement pigs (Honeyman and Harmon, 2003).

Several studies on pork carcass measurements of pigs finished in outdoor housing systems have been documented. Warriss *et al.* (1983) and Enfält *et al.* (1997) reported that outdoor-reared pigs had thinner backfat measurements compared with pigs reared intensively indoors. Van der wal (1991) showed that free range reared pigs had similar growth and carcass composition compared with littermates finished indoors, on partially slatted floors. It has been suggested that if pigs are reared outdoors in cold conditions, then carcasses may have less fat because food is diverted from fat deposition to thermoregulation (Warriss, *et al.,* 1983; Sather *et al.,* 1997; Edwards, 1999). Other researchers have determined that pigs reared outdoors had reduced water holding capacity, lower ultimate pH, and/or higher shear force values than pigs reared indoors (Barton-Gade and Blaabjerg, 1989; Enfält *et al.,* 1997), while others report no commercially important differences in meat quality of pigs reared outdoors compared to pigs reared indoors (Van der Wal, 1991; Van der Wal *et al.,* 1993; Sather *et al.,* 1997). Enfält *et al.* (1997) reported reduced tenderness and juiciness in the loin muscle of outdoor reared pigs during the winter months. Jonsäll *et al.* (2001) reported that ham from outdoor reared pigs was less juicy and acidulous than ham from indoor reared pigs but no differences were found in tenderness, odour intensity, or meat taste between the indoor and outdoor reared groups. Maw *et al.* (2001) reported that pigs housed on straw bedding produced bacon with a stronger fried meat flavour than bacon from pigs housed on concrete or slats.

Gentry *et al.* (2002b) found decreased shear force values in the loin for outdoor-reared pigs, indicating a small advantage in objective tenderness among pork from outdoor pigs. Loin shear force values indicated a tenderness advantage for outdoor-reared pigs, however, these results did not agree with sensory panel scores. Increased exercise levels may play a role in pork tenderness since pigs were required to walk greater than 350 m from the waterer to the feeder. These results agree with Beattie *et al.* (2000a) who found that pigs from enriched environments produced pork with a lower shear force than their counterparts from barren environments. Other researchers have found no effect of physical activity on sensory qualities of cuts from the ham and loin (Essén–Gustavsson *et al.,* 1988; Van der Wal *et al.,* 1993; Petersen *et al.,* 1997), but the degrees of exercise and enrichment of the environments varied.

5. Research opportunities to improve grow-finisher pig welfare

Because the G-F period represents both the longest time in the life cycle of the growing pig and because this phase represents the largest input in terms of feed and other costs, the G-F phase is a very important phase to garner improvements in both performance, health and overall welfare. In the G-F phase, the facility, the level and types of human interaction and the management practices have a direct effect on pig welfare.

Assuming the G-F phase does not include detrimental human handling, facilities, genotypes or poor health, the primary opportunities for improvement of animal welfare are in the areas of environmental enrichment, space allowances for the finisher pig and pig handling/people training. The G-F pig typically experiences a dull, non-stimulating environment. Finding appropriate stimulation, especially tactile and olfactory stimulation would be positive. Second, G-F pigs often have a stressful transportation and pre-slaughter experience at the end of the G-F phase. Anything that can be done to pre-condition the pigs might minimise the stressfulness of these last experiences.

6. Conclusions

The addition of environmental enrichment or the use of alternative production systems such as hoops and other bedded systems for finisher pigs provide an opportunity for premium marketing of meat products and enhanced animal welfare of the livestock. In addition, similar performance and meat quality measures can be expected when comparing pigs housed in confinement and alternative systems. Animal welfare benefits include increased space allowance and the presence of natural bedding. The success of these systems will depend on customer and consumer demand for premium products and environmental adaptations of a producer with an appropriate production system.

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Chapter 6. The welfare of pigs during transport

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Abstract

Choosing the appropriate space allowances for slaughter pigs during transport has become an issue as, on one side, there is economical pressure to increase stocking densities in order to make maximum profit from a single journey, i.e. the more pigs transported, the lower the unit cost. On the other side, animal welfare (mortality) and carcass and meat quality may be compromised at too high or too low stocking densities. Market pigs can experience higher mortality (e.g. due to heat stress), injuries (bruises) and lower meat quality if the space allowed is not appropriate. Transport distances are largely governed by the availability of pigs in the region around the abattoir. However, journey times are likely to increase with the concentration of the slaughtering industry into fewer, larger plants for economic reasons. Pig welfare during transit is also highly dependent on vehicle design, driving method, quality of the road being travelled, ambient temperature, ventilation, noise levels and vibration of the vehicle. In 2006, the World Organisation for Animal Health (OIE) recommended animal transport times be kept to a minimum with sufficient space allowance for animals to lie down during transport, with consideration given for climate and ventilation capacity of transport vehicles. It is anticipated that global livestock welfare transport standards will follow.

Keywords: behaviour, meat quality, pigs, transport, vehicle design, welfare

1. Introduction

In May 2006, the 169 member nations of the World Organisation for Animal Health (OIE) voted to adopt new standards for the land and sea transport of live animals, including pigs (OIE, 2006). The new OIE revised guidelines recommend animal transport times be kept to a minimum with sufficient space allowance for animals to lie down during transport, with consideration given for climate and ventilation capacity of transport vehicles. Furthermore, the OIE also voted to investigate the implementation of global livestock welfare transport standards. As such, it is necessary for countries to review and revise their livestock transport regulations and guidelines in anticipation of such changes as a means of retaining foreign market access and improving the welfare of animals in our care.

During the time between leaving the farm and slaughter, animals are subjected to removal from familiar surroundings, loading and unloading from vehicles, and transport. Transportation is a novel situation for pigs and, as such, is capable of provoking apprehension. Actually, it exposes the animals to several new potentially stressful factors, such as unfamiliar noises and smells, vibrations and sudden speed changes of the truck, variations of environmental temperature and lower individual social space. Such stressors often elicit both behavioural and physiological responses which can contribute to a reduction in carcass yield and meat quality.

2. Loading density

Loading density is the extent to which animals experience crowding during transportation, and scientific measurements of this animal experience of crowding are often difficult to achieve. However, loading density is one of the most easily-manipulated and regulated variables in the transportation of pigs. Recommended loading densities for pigs during transport are often a compromise between economic pressure to increase loading density in order to maximise profit from a single journey (i.e. the more pigs transported, the lower the unit cost) and the welfare of an animal (in addition to carcass and meat quality). Decisions about loading densities on pig transporters are usually made by the pig producer and the contracted hauler, who are likely to be primarily influenced by economics. Legislated and recommended loading densities are not always met in practice (Aalhus *et al.*, 1992) as the chosen densities are adjusted to the different transport conditions (weather, road type, distances, pig breed and size) among the different countries.

2.1. International regulations and guidelines

Amongst current international regulations and guidelines, a consensus exists on two key points in regard to loading densities of pigs during transport. The first agreement is on the need to partition animals in order to minimise injury during transport. The second consensus is on the need to reduce pig loading densities (increase space allowance) during warmer weather (above 24 °C). However, there is no firm agreement on how much loading densities should be reduced during warmer weather.

Recently, an expert group of the Scientific Committee on Animal Health and Animal Welfare reviewed the welfare of animals during transport and identified a number of problems associated with current transportation practices and rules (SCAHAW, 2002). Aside from the role of transport in infectious disease transmission, details on loading density and interactions between loading density, vehicle design and meteorological conditions are not yet known. Handling and transportation are considered major stressors for farm animals (as reviewed by Grandin, 1997, 2003; Knowles and Warriss, 2000; Von Borell, 2001) and might have deleterious effects on the health, well-being, performance and ultimately product quality of pigs (McGlone *et al.*, 1993; Bradshaw *et al.*, 1996a; Schütte *et al.*, 1996; Geverink *et al.*, 1998a,b). Most studies on farm animals have been concerned with stress during animal handling and to a lesser degree on transportation stress per se (Von Borell and Schäffer, 2005).

Many recommendations on loading densities for pigs during transport aim to base their conclusions on scientific information, and, if possible, scientific reports are prepared by independent experts. This is often the case in the EU (Le Neindre *et al.*, 2001). However, these recommendations are not always translated into national regulations. For example, EU 95/29/EC specifies that floor pressure for 100 kg pigs should not exceed 235 kg/m^2 (space allowance of 0.425 m^2/100 kg) and that a maximum increase of 20% (0.510 m^2/100 kg or 196 kg/m^2) may also be required depending on meteorological conditions and journey time.

2.2. Loading density equations

One criterion for acceptable loading densities is based on the provision of adequate ventilation. Another is the minimum space required for animals based on dimensions and activities during transport, including loading and off-loading of animals. The Canadian Recommended Code of Practice for Care and Handling of Pigs (AAFC, 1984) suggests an area per 100 kg pig of 0.34 m^2 for outside temperatures below 16 °C, 0.38 m^2 for temperatures between 16-23 °C and 0.41 m^2 for temperatures above 24 °C. These values are consistent with space allocation equations derived by Randall (1993). However, it should be cautioned that Randall (1993) was interested in only the environmental parameters necessary to define comfort for animals, such as pigs, during transport. One of Randall's big concerns was that at higher loading densities, ventilation may be impaired due to the obstruction of vents on the truck since livestock need to be given adequate headroom for sufficient air distribution (Randall, 1993). The equations provided by Randall (1993) are only best estimates of overall space needed by a relatively large group. However, Randall's formula has been used as the basis for space allowance recommendations in countries such as Canada in the past (Whiting and Brandt, 2002).

One problem with providing loading density equations is that the dimensions used are static dimensions and do not necessarily provide adequate room to allow animals to change position or posture in order to keep balance and interact with others. In the case of pigs, there are two aspects of space that are critical, the area they lie and/

or stand in, and the volume of air available to the animals. Loading density, as it is properly notated, is kg/m^3 which is a measure of volume. However, it has been noted that using volume alone is inadequate since one could theoretically provide very little floor area and a high ceiling, so the pigs have adequate air but are unable to lie down during transport (H. Gonyou, Prairie Swine Centre, Canada, personal communication). In comparison, space allocation is commonly notated as kg/m^2, but an alternative expression has also been suggested. Von Borell and Schäffer (2005) recently proposed the allometric equation of $A = 0.0192 * BW^{.667}$, which is similar to equations used in determining floor space within barns. However, in the case of barn stocking densities, the (k) coefficient differs from transport loading densities. The advantage of Von Borell and Schäffer's (2005) allometric equation is that it allows transporters to use one k-value across all weight ranges, rather than changing the kg/m^2 value as is currently necessary (H. Gonyou, personal communication). Similar equations have been provided in earlier studies by Petherick and Baxter (1981) and Petherick (1983).

2.2. Mortality, injury and welfare

There is no doubt that deaths occurring during transport indicate a clear compromise of animal welfare. Market pigs experience higher mortality (heat stress), injuries (bruises) and lower meat quality if the space allowed is not appropriate (reviewed by Faucitano, 2000). This is particularly true during hot and humid weather when mortality rates can be even higher (Dewey *et al.*, 2004). Robertson (1987) found that mortality was highest (0.54%) when groups of pigs were transported at the 'recommended' vehicle loading densities or higher. Furthermore, mortality rates decreased progressively as the loading density was reduced from between 90 to 99% of the recommended (0.34% mortality) to between 80-89% (0.17% mortality). Work from Spain tends to support these results. Guàrdia *et al.* (2005) reported an increase in the incidence of skin blemishes due to crushing and/or aggression when more than 0.35 m^2 per 100 kg pig was given during transport. In an earlier study, Guàrdia *et al.* (1996) found that transporting pigs at space allowances greater than 0.40 m^2 per 100 kg pig increased the mortality rate from 0.04 to 0.77% under Spanish commercial conditions. Riches *et al.* (1996a,b) found similar results in the UK.

At floor pressures greater than 238 kg/m^2 in the UK, mortality rates were found to increase (Riches *et al.*, 1996a). Warriss *et al.* (1998b) speculated that the increased mortality rates at higher floor pressures may be due to the greater physical stress to the pigs based on the increased activity of the enzyme creatine phosphokinase (CPK) in the blood. While Barton-Gade and Christensen (1998) found CPK levels to increase with higher loading densities, lactate, which is another measure of physical stress, was not affected. However, Barton-Gade and Christensen (1998) concluded that there was relatively little effect of increasing loading density on blood profile (when measuring stress-correlates). In contrast, Warriss and colleagues (1998b) concluded that a floor pressure of 321 kg/m^2 (approx. 0.31 m^2/pig) is unacceptable for the transport of pigs.

Overall, market pigs can experience higher mortality (e.g. from heat stress), injuries (e.g. bruises) and lower meat quality if the space allowed is not appropriate. Higher stocking densities (0.30-0.31 m^2/100 kg pig or 323-333 kg/m^2) with journey times up to three to four hours have resulted in more physical stress to pigs based on the activity of the enzyme CPK in the blood (Warriss *et al.*, 1998b) and increased rectal prolapse (Guise and Penny, 1989b) and mortality rates (up to 0.77%; Guàrdia *et al.*, 1996). However, overcrowding is not always detrimental to pig welfare. Based on the cortisol variation in blood, Oliver *et al.* (1996) concluded that the application of high stocking densities (< 0.40 m^2/100 kg) helps pigs to maintain the body temperature when transported by open-sided trucks in winter (Figure 1).

2.3. Behaviour

A number of studies have documented the psychological component of the welfare of animals during transport (reviewed by Le Neindre *et al.*, 2001). In addition to the physical conditions animals experience during transport, a main objective has been to understand the way the animal perceives the situation. The most sensitive tool to appreciate the animal's subjective emotional state is usually behaviour (Jensen and Toates, 1993).

Figure 1. High densities may affect the pig comfort during transport (Photo courtesy of Luigi Faucitano).

Loading density has an important influence on the behaviour of pigs during transport (Barton-Gade and Christensen, 1998; Faucitano, 2000). Directive 95/29/CE and Council Regulation (EC) No. 1/2005, concerning the protection of animals during transport states that all pigs must be able to lie down and stand up in their 'natural' position. Overall, scientific studies have supported that the floor pressure for pigs around 100 kg should not exceed 235 kg per m^2 or 0.425 m^2 per 100 kg pig in order to comply with these minimum requirements. However, studies have reported contradicting results on whether pigs stand or lie down during transport, thus affecting the space required for animals to assume their 'natural' position during transport. Hunter *et al.* (1994) reported that the great majority of pigs stand during transports of unspecified lengths. In the mid-1990's, this same research group reiterated their view that most pigs stand while the transport vehicle is moving, only lying down when the vehicle is stopped (Riches *et al.*, 1996a; Guise *et al.*, 1998). In contrast, Bradshaw *et al.* (1996d) observed that most pigs lie down and rest after the initial 2-4 h of transport. Other studies have found that once pigs have adapted to the new situation, animals prefer to lie down if sufficient space is available (Baxter, 1985; Lambooij and Engel, 1991). Specifically, Lambooij and Engel (1991) investigated the effect of transporting pigs over long distances (25 hrs) and reported that pigs searched for a suitable place to sit or lay down after the start of transport, with pigs lying the most overnight and during stops. Furthermore, the authors found that activities were influenced by the loading density. At greater space allowances (0.59 m^2/pig), pigs were observed lying down earlier in transport with the number of lying pigs remaining high compared with lower space allowances of 0.39 or 0.47 m^2/pig. At a space allowance of 0.47 m^2/pig, all pigs were observed as having just enough room to lie down, but it took pigs longer to do so. At the lowest space allowance (0.39 m^2/pig) investigated by Lambooij and Engel (1991), not all pigs were found to be able to lie down during transport, which resulted in continuous position changes and animals not being able to rest.

Lambooij *et al.* (1985) reported that at space allowances as large as 0.66 m^2/pig, pigs tend to lie down within 2 hours of the start of a journey. Another study found that giving more space (0.42 and 0.50 m^2/pig) during short transports (approx. 2 hrs) does not necessarily result in more pigs lying down, and may cause more disturbance and difficulties for pigs maintaining their balance when the vehicle negotiates bends or poor road surfaces (Barton-Gade and Christensen, 1998). At high compartment floor pressure (> 250 kg/m^2 or < 0.39 m^2/pig), continual disturbance of recumbent animals by those seeking a place to rest has been observed (Lambooij and Engel, 1991). This unrest, in turn, promotes mounting behaviour which provokes aggressive behaviour leading to higher skin damage scores (Guise and Penny, 1989a). Thus, it seems that both high and low loading densities can be likely sources of skin damage as well as rectal prolapse.

2.4. Meat quality

Two main problems with regard to meat quality in pigs, PSE (pale-soft-exudative) and DFD (dark-firm-dry) meat, can be indicative of acute (e.g. PSE) and chronic (e.g. DFD) stress being suffered during transport (Guàrdia *et al.*, 2004, 2005). PSE meat occurs when animals suffer acute stress prior to slaughter (Oliver *et al.*, 1988) and the pigs respond with a rapid increase in lactic acid (lowering muscle pH to below 6.0 within the 1st h post-mortem; Briskey, 1964; Eikelenboom *et al.*, 1976) during the immediate post-mortem period due to sufficient energy reserves still being available. In contrast, DFD meat occurs when animals suffer chronic stress and use up all their energy which prevents sufficient lactic acid from reaching muscle pH values lower than 6.0 within 24 hours of slaughter (Tarrant, 1989). DFD meat is also a food safety concern because it causes both bacterial spoilage in fresh meat (e.g. lower shelf life in the refrigerator case) and causes technical problems during the dry-curing process (Wirth, 1985).

Many studies have been conducted on the detrimental effects of high loading density on animal welfare and meat quality in pigs (Dantzer, 1982; Von Mickwitz, 1982; Guise and Penny, 1989a; Lambooij and Engel, 1991; Warriss *et al.*, 1998b). There is conflicting evidence regarding the effects of very high loading densities on meat quality, given the overlapping effect of genetics and distance transported. However, for longer journeys (25-44 h), there is evidence that high floor pressures (> 250 kg/m^2) affect meat quality and carcass yield detrimentally. Based on these findings, Lambooij and Engel (1991) recommended a floor pressure of 232 kg/m^2 (i.e. for a 110 kg pig, 0.47 m^2 space allowance). Hunter *et al.* (1994) reported a significant interaction between season and loading density for rigor, skin blemish, ultimate pH and ultimate colour, with transportation in the summer having the greatest.

While Barton-Gade and Christensen (1998) found only a slight effect of loading density on meat quality when varying the space allowance between 0.35 and 0.50 m^2/100 kg pig for journeys less than 3 h, a recent study by Guàrdia *et al.* (2004) found an interaction between space allowance and transportation time as it affects the risk of developing PSE. On average, transportation time has been found to decrease the risk of developing PSE (2.9% per hour) while the availability of space during transport increases this risk (1.7% per 0.1 m^2/100 kg pig). Thus, the highest risk of PSE occurs in short transits utilising higher space allowances (0.50 m^2/100 kg pig) and the lower the space allowance, the lower the effect of transportation time. It is possible that lengthening transport time reduced the incidence of PSE meats (Fortin, 1989; Pérez *et al.*, 2002) because it allowed pigs to recover from the stress of loading and to adapt to the new environment. During the initial hours of transport, pigs are still primed for confrontation and fighting, a circumstance that may occur more frequently if pigs have more space to move around (Guàrdia *et al.*, 2004). Once pigs have adapted to the new situation, pigs prefer to lie down if sufficient space is available (Baxter, 1985; Lambooij and Engel, 1991). Such results indicate that lowering loading density (i.e. increasing space allowance) for the purpose of reducing PSE carcasses would only be advisable for long transports, such as those over 7 h (resulting in a 3% reduction in PSE; Guàrdia *et al.*, 2004). In contrast, Guàrdia and colleagues warn that for transits of only 1 h, a reduction in loading density actually increases the risk of PSE by about 3%. The authors caution that previous studies reporting a detrimental effect of loading density on PSE (Guise and Penny, 1989a; Nanni Costa *et al.*, 1996) should be interpreted in the light of this result. As such, Guàrdia *et al.* (2004) recommend that in order to prevent PSE, a space allowance of 0.425 m^2 per 100 kg pig (such as that recommended by the EU) is only appropriate for journeys longer than 3 h.

Guàrdia *et al.* (2005) investigated the risk of DFD meat according to transport loading density. The results obtained show the potential negative effect that excessive space allowance may have on the occurrence of DFD meat. Reducing the space availability from 0.50 to 0.37 m^2 per 100 kg pig represented about an 11% decrease in the risk of producing DFD meat. According to Barton-Gade (1996), 0.45 m^2 per 100 kg is excessive for short journeys. Barton-Gade and Christensen (1998) suggested that the negative effect of providing pigs with too much space during transport may be due to animals being thrown around, getting stuck and bruised as a result of unexpected movements of the transport vehicle. Likewise, muscle fatigue and glycogen depletion due to confrontation and fighting make animals more prone to DFD. Contrary to results obtained for PSE (Guàrdia *et al.*, 2004), the logistic model for DFD in the results of Guàrdia *et al.* (2005) did not include the loading or transport time, nor the interaction between transport time and loading density.

A space allowance of 0.425 m^2/100 kg pig was suggested by Lambooij *et al.* (1985) as a suitable compromise between welfare, meat quality and transport economy for long distances. Later on, Lambooij and Engel (1991) recommended a space allowance of approximately 0.47 m^2/ pig (232 kg/m^2) for similar reasons. Thus, based on the scientific literature, current space allowance standards should be close to, but not exceed, 0.425 m^2/100 kg in order to reduce the risk of producing either PSE or DFD meat. However, results obtained by Guàrdia *et al.* (2004) showed that, in terms of PSE, a space allowance 0f 0.425 m^2/100kg pig is only appropriate for journeys longer than 3 h. These results, in conjunction with that obtained by Guàrdia *et al.* (2005), indicate that, for journeys shorter than 3 h, increases in the availability of space during transportation raise the risk of both DFD and PSE pork due to the stress of loading and time needed for animals to settle down. In contrast, for journeys of longer than 3 h, a balance between the risks of producing PSE and DFD is needed, as in this case increasing the space allowance during transport has an unfavourable effect on DFD but favourable effect on PSE.

3. Transport distance and duration

In the last few years, the centralisation of the slaughtering industry, with more animals being killed in fewer larger plants, has modified the distance that animals must be transported to the slaughterhouse. In a transport survey conducted in Europe from 1992 to 1995 (AIR3-CT92-0262), the majority of pigs in all countries travelled less than about 2 h with average distances of 100 km or less. In British and Spanish surveys the average transport times were almost the same but the average distances were twice as much (Gispert *et al.*, 2000; Riches *et al.*, 1996b). In contrast, the most recent Canadian pig transport survey (Aalhus *et al.*, 1992) found that while the majority of pigs were transported less than 3 h, 4% of pigs in Canada were transported more than 24 h. However, due to increased regionalisation of packing plants in Canada over the last 15 years, it is speculated that a larger percentage of pigs are long-haul transported, particularly between Canada and the United States.

In general, it is accepted that the duration of the journey is an aspect of transport that can affect the welfare (Lambooij and Van Putten, 1993) and meat quality of pigs (Grandin, 1993; Hevia *et al.*, 1995; Bradshaw *et al.*, 1996c; Warriss *et al.*, 1998a). It has been suggested that the best course of action would be to slaughter pigs before any transport takes place since pigs are sensitive to journeys of short and long duration and are prone to travel sickness (Bradshaw *et al.*, 1996c) and disease (Nabuurs, *et al.*, 2001). In particular, Nabuurs *et al.* (2001) reported that even short duration transportation can lead to small intestinal acidosis, which predisposes animals to bacterial translocation. Therefore, there is scientific evidence that even short-haul transport of pigs should be avoided when possible. Since not transporting animals is not practically possible, the need to answer the question of duration of journey is pressing and is crucial to our understanding of the needs of pigs during long distance road transport.

3.1. International regulations and guidelines

Amongst current international regulations and guidelines, a consensus exists on five key points in regard to transport duration for pigs, including:
- Loading and unloading of pigs is recognised as being extremely stressful for the animals.
- As such, trips can be extended in many cases for up to two additional hours if vehicle is within two hours of the final destination.
- All regulations and guidelines recognise that animals being transported have a feed and water requirement.
- Special consideration is given for very young and pregnant animals.

Transport duration may be further limited depending on the type of vehicle pigs are being transported in (e.g. basic versus 'higher standard').

3.2. Mortality, injury and welfare

Von Mickwitz (1982) stated that deaths in transit should be considered the worst result of an extreme physiological reaction. He further speculated that even when only one pig on the transport vehicle dies, it is possible that the welfare of all other pigs on-board the transport vehicle is reduced. In a retrospective study, Palacio *et al.* (1996) found that trip duration is a risk factor for pig's mortality, with the highest mortality rates observed when pigs were transported 50-150 km. This is an evident indicator of poor welfare during transport (Warriss and Brown, 1994; Warriss, 1995; Guàrdia *et al.*, 1996; Colleu and Chevillon, 1999).

Pérez *et al.* (2002) reported lower cortisol concentrations in Spanish pigs transported for 3 h compared with animals transported for only 15 minutes. Based on this and other findings, the authors suggested that pigs may eventually adapt to travel if conditions are good. However, the authors concluded that under normal Spanish commercial conditions, pigs subjected to short transport showed a more intense stress response than pigs subjected to moderately long transport. Pérez *et al.* (2002) further suggested that transporting pigs for longer durations might have allowed the animals to adapt to transport conditions. However, the maximum transport duration investigated in their study was only 3 hours.

Barton-Gade and Christensen (1998) observed that pigs increasingly began to sit and lie down after 20-30 minutes of transport. However, these findings do not agree with those of Bradshaw *et al.* (1996c) who found that pigs do not settle down until 5 h after transport has commenced. Dalin *et al.* (1993) found that plasma cortisol levels rose immediately after the start of transport and did not decrease until after unloading. However, the study by Dalin and colleagues only included 6 gilts of 134 kg body weight, and animals were only transported for 60 minutes. A later study by Bradshaw *et al.* (1996d) also found increased levels of cortisol, but the journey time (1.5 and 8 hours) led them to the conclusion that this rise, initially a response to loading, was maintained as a response to transport. These authors reported that cortisol levels remain high for the first 5 h of an 8 h journey, suggesting that pigs find long distance travel stressful, which is further confounded by both fighting after mixing with unfamiliar pigs as well as the effects of travel sickness (Bradshaw *et al.*, 1996a). In a similar study, Bradshaw *et al.* (1996c) also found cortisol levels were higher when pigs encountered rough periods in transport compared with either smooth journeys or when the transporter was stationary. Warriss *et al.* (1998a) observed that pigs transported from farms over long distances (> 120 km) had higher cortisol concentrations than those travelling from farms only a short distance away (< 10 km). This difference could be due to the effects of the farm as well as travelling conditions. Lambooij (1988) studied the effect of even longer journeys of 25 hours on the stress response in pigs, but the study did not make clear whether long-distance transport is, in itself, stressful.

Piñeiro *et al.* (2007) provides a good example of how the long-haul transport of pigs under good conditions can actually be better for the welfare of animals in transit compared with short-hauls. Piñeiro and colleagues evaluated the acute phase protein (APP) during transports of either 24 or 48 hours under commercial conditions. Elevated serum APP concentrations were observed in 2 groups of boars immediately after their arrival at a destination farm. The effect was more pronounced in pigs shipped 24 hours under average transport conditions even though the second group of pigs was transported for a longer time period (48 hours) under superior conditions. These results nicely demonstrate how conditions on the transport vehicle can affect an animal's perceived stress, which has an impact on how long animals can be transported before welfare is severely compromised.

3.3. Rest periods, food and water

Transport distances are largely governed by the availability of pigs in the region around the abattoir. However, current journey times are likely to be longer with the concentration of the slaughtering industry into fewer, larger plants for economic reasons (Warriss, 1994). The recommendation of the EU Working Group on pig transport is that minimum transport times should be aimed for and a maximum acceptable journey limit might be 3 h (Warriss, 1995). However, it seems that a total journey time between 8 and 16 h under good conditions, even without access to water, appears to be acceptable from an animal welfare point of view (Brown *et al.*, 1999). However, Brown and colleagues found that pigs still appeared to become dehydrated after longer journeys, as indicated by increases in the concentrations of plasma total protein and albumin but not in osmolality. The most severe dehydration occurred in pigs transported for 24 hours. Furthermore, even when provided drinking water during lairage, Brown *et al.* (1999) noted that dehydration remained a problem at the time of slaughter. In cases of long journeys, transport can be prolonged up to 24 h, provided transport conditions (i.e. ventilation and density) are good and water is available. These recommendations are reflected in current EU guidelines in which transport duration limits are determined by the type of vehicle and whether it is 'basic' or 'higher standard'. Table 1 provides an overview of international standards, voluntary and mandated, concerning pig transport journey duration, including the provision of feed, water and rest periods during transit.

Table 1. Comparison of regulations and recommendations for different regions on providing rest, water and food during pig transport.

	Type	Time without rest, water and/or feed	Specifics of food, water and rest
CAN[1]	Regulations and guidelines	Maximum of **36 h**, not to exceed 40 h Iso-weaned piglets not to be transported more than 12 h to nursery facility	Pigs must be fed prior to loading for trips over 12 h 5 hours for feed, water, rest between two transport periods Nursing young provided with additional feed and water every 8 h
USA[2]	Guidelines	**48 h** transport for mature pigs (but 30-40 h should be better)	Experienced transporters recommend 8-12 h of rest after a 24-h (or more) transport
AUS[3]	National guidelines	No set maximum journey duration for pigs No deprivation of food or water	Access to food/water every 24 h, preferably every 12 h, with piglets provided water more often (at least every 12-h) Pigs are to be rested for 12-24 h after 24-h of travel Pigs to be given food and water immediately upon arrival at final destination
NZ[4]	Guidelines	No more than **14 h** in pigs Water every **8 h** Feed every 24 h	Rest period of at least 12h after a 8h transport for pregnant sows
EU[5]	Regulations	No more than **8 h** except for suitable vehicle and in this case, 24 h (with continuous access to water) Journey times may be extended by 2 h, depending on proximity to final destination.	After 24 h, animals must be unloaded, fed and watered for at least 24 h. After the whole journey, minimal resting period of 24h with food and water
UK[6]	Regulations	Maximum of **8 h** (basic vehicle) On higher standard vehicles, maximum of 24 h transport (with continuous water) Maximum of 8 h between transport legs when transporting pigs to or from markets	After 8 h transport on a basic vehicle, 24 h rest period required After 24 h on a higher standard vehicle, 24 h rest period required Time at markets must meet the definition of a mid-journey rest

Table 1. Continued.

	Type	Time without rest, water and/or feed	Specifics of food, water and rest
IR[7]	Regulations	No maximum transport time for pigs	
SA[8]	Guidelines	Animals should arrive at final destination as soon as possible after transport begins Must arrive at destination during business hours Drivers not permitted to stop for more than 30 minutes at a time Animals not to be restrained for more than 4 h out of every 24 h.	Sufficient supply of water for emergency use on trips over 50 km

Sources: [1] Department of Justice Canada, 1990 & CARC, 2001; [2] AMS-USDA, 1997, [3] SCAHAW, 2002; [4] AWAC, 1994; [5] CEC, 1991; 2005, [6]S.I. 1997 No. 1480; [7]DAF, 2003; [8]LWCC, 2003.

In the EU, after 24 h (with continuous access to water) pigs must be unloaded, allowed to rest for 24 h and provided with food before continuing the journey (95/29/EC). In Canada, the minimum resting time is 5 h (AAFC, 1993) after 36 h of transport. This discrepancy in international standards is due to the fact that a minimum resting time after long transportation is not yet established (Faucitano, 2000). In addition to the length of rest periods, another consideration is the stress of loading and unloading animals for rest periods during transport. En-route rest periods involve mixing unfamiliar animals in a novel environment, which may not provide suitable facilities or favourable weather conditions. Provaznik and Valenta (1994) found that providing pigs with a prolonged rest period (over 18 h) had a positive effect, using muscle pH as a measure of pork quality, in those animals transported over 41 km. However, evidence from Bradshaw *et al.* (1996a) suggests that, because loading and unloading is a very stressful period, and the animals become travel sick, unloading the pigs during a long distance journey in order to rest them and allow them food and water (and subsequently re-loading them back onto the vehicles with full stomachs), may be the worst possible course of action. Even when feed is available in the truck, it has been reported that pigs eat from 2 to 5 times more during the truck stops than when the transport vehicle is in motion (Chevillon *et al.*, 2003). This justifies the recommendation that after 24 h journey, pigs must be allowed to rest for at least 8 hours and provided with light rations (2.3 kg of thin porridge consisting of one part feed and three parts water) before continuing the journey (Lambooij, 2000; SCAHAW, 2002). Feeding and watering pigs on the truck would avoid the stress of unloading and mixing in the staging point compartments (Lambooij, 2000; Chevillon *et al.*, 2003).

This recommendation is also supported in an earlier pig transportation review by Tarrant (1989). Tarrant (1989) concluded that because the main stresses in pig transport are at loading and unloading, short journeys may be more detrimental than longer ones, particularly if the driving, loading density and ventilation is good (e.g. higher standard vehicles are used). The stress response exhibited at and just following loading may be due in part to the novelty of the environment the animals enter (reviewed by Hall and Bradshaw, 1998). In an earlier study, Augustini and Fischer (1982) found heart rates were highest at loading and unloading in German Landrace pigs of 100 kg liveweight. Furthermore, the study found the highest heart rates occurred during assembly and loading when body temperatures were also found to increase rapidly. However, Augustini and Fischer (1982) also reported that under good transport conditions, body temperatures were able to return to normal by the end of a 100 minute transport journey, even when ambient temperatures were as high as 29 °C. It is important to note that the authors did not find the same to be true when space allowances were considered low (0.35 m^2/100 kg). At lower space allowances, rectal temperature during transport was greater and the return to normal was delayed (Augustini and Fischer, 1982; Von Mickwitz, 1982).

Various studies have reported that rate of dehydration is greatly accelerated by road transportation (Warriss *et al.*, 1983; Becker *et al.*, 1989). Becker *et al.* (1989) suggested that because feed and water deprivation requires changes in energy metabolism and fluid regulation, extended transportation times could be expected to place greater demands on these physiological systems. Specifically, Becker *et al.* (1989) found that pigs transported with a fast of 48 and 72 hours resulted in higher hematocrit readings than pigs that were fasted without transport. The authors concluded that these results demonstrate increased dehydration associated with transport. Becker and colleagues (1989) further speculated that the greater state of dehydration was likely the result of water lost through enhanced respiratory vaporisation and higher water turnover associated with physical activity during transport as well as the stress of adjusting to a new environment. Warriss *et al.* (1983) cited increased water consumption in lairage for pigs transported 6 hours, compared with animals transported only 1 hour, and decreased carcass yield as possible evidence of water deprivation occurring during longer transport journeys. Once animals become dehydrated, muscle tissue mass can be lost since muscle tissue is about 75% water (Tarrant, 1989). In particular, Becker *et al.* (1989) reported a significant decrease in loin muscle area.

However, provision of water on transport trucks has not always resulted in pigs drinking more during transport. During 29 h transport from The Netherlands to Italy, Lambooij *et al.* (1985) found that pigs drank only 0.65 liters of water each, whereas under normal housing conditions 100 kg pigs will drink 7-20 litres per day. The authors suggested that the low water intake may have been connected with the absence of food and/or dislike of drinking from bite nipples in a shaking truck. The EC Working Group in 1992 (EC Working Group, 1992) on transport of farm animals recommended that, for welfare reasons, pigs should have access to water and a one hour rest period every 8 hours. Physiological data do not support this recommendation, but since some pigs will drink, then one could argue that pigs should be given the opportunity to do so.

3.4. Meat quality

Higher lactate concentrations found in pigs transported over a shorter distance may be an indicator of physical stress and may explain why Pérez *et al.* (2002) found lower pH values in such animals. The authors reported that pigs transported for only 15 minutes showed significantly lower pH values in various muscle groups and a higher tendency to produce PSE meat compared with animals transported for 3 hours. In pigs, PSE meat is a major quality defect associated with abnormal post-mortem muscle acidification. Valenta and Provaznik (1996) also described higher incidence of PSE meat after short transport (< 40 km) although they rested the pigs for 1-4 h before slaughter. Other authors have found that when transport distance increased, the incidence of meat with high ultimate pH increased (Scheper, 1971). Martoccia *et al.* (1995) reported that distance travelled (650 km and 180 km) also affects pH values and Meller (1992) found reduced meat quality for longer transport distances. In an Australian study, McPhee and Trout (1995) also found meat quality problems due to long transport. Specifically, the authors concluded that the imposition of long-term transport stress before slaughter increased DFD meat in pigs. However, Warriss *et al.* (1983) found a lack of effect of transport time on ultimate muscle pH. Likewise, Fernandez and Tornberg (1991) conducted a wide review of the causes of variation of ultimate pH in pigs and observed that it was difficult to draw a conclusion regarding the effect of transport time because of the different results obtained from different authors, which points to the fact that several factors interact. What is agreed upon amongst various studies is that pigs transported for shorter distances may need longer lairage time as resting time (Pérez *et al.*, 2002).

Leheska *et al.* (2002), after studying the affect of the fasting time x transport length interaction on pork quality, found that the effect of length of transport was greater in magnitude than the effect of duration of fasting. Shorter transports (< 1 h) may be more detrimental than longer ones as pigs must be given the time to recover from the stress of loading (Bradshaw *et al.*, 1996b,c) and to acclimate to the stress of transport (Stephens and Perry, 1990). It has been observed that pigs hauled very short distances for under 30 min are less easy-to-handle at the plant and may produce poorer pork quality (ex: PSE) than pigs transported for longer distances (Grandin, 1994; Pérez *et al.*, 2002). Park *et al.* (2003) reported that transports longer than 1 h decreased the incidence of PSE pork by 9%. However, this effect depends on the loading density applied.

4. Vehicle design

Pig welfare during transit is highly dependent on vehicle design and driving method as well as the quality of the road being travelled. It has been evidenced that the deck and transport compartment environment have an impact on welfare, skin blemishing and meat quality. Pigs transported either in the front or rear compartments have been shown to produce poor meat quality (PSE or DFD) and have higher body weight losses, carcass bruises and lactate levels compared with pigs travelling in central pens (Guise and Penny, 1989a; Barton-Gade *et al.*, 1996; Dalla Costa *et al.*, 2006, 2007). A higher mortality rate is usually reported in the front compartment, immediately behind the driver cabin, where the ventilation rate is poor and the vibration level is high (Riches *et al.*, 1996b; Christensen and Barton-Gade, 1999). Moreover, pigs transported in lower decks can either show a greater PSE-incidence, particularly when the pen is poorly ventilated (Guise and Penny, 1992), or a tendency to DFD meat, which is possibly due to the effects of physical stress caused by the necessity to keep the standing position in order to cope with the high level of vibrations (Barton-Gade *et al.*, 1996; Randall *et al.*, 1996). Skin damage score is also higher in these pigs as standing pigs are more subject to falling or trampling and, thus, can be injured during transport (Barton-Gade *et al.*, 1996). Finally, the lower deck effect has an impact on the pig welfare during transport. Pigs transported on the lower deck have higher body temperature and blood cortisol levels and show a higher degree of dehydration (Lambooij *et al.*, 1985; Lambooij and Engel, 1991; Barton-Gade *et al.*, 1996). A higher incidence of deaths in transit has been also reported on the lower deck (Christensen and Barton-Gade, 1999).

4.1. Vehicle structure

To optimise transport conditions, the transport vehicle should have a covered deck (ceiling and sides), effective mechanical ventilation and ventilation openings both low down and high up semi-automatically adjusted from the driver's cabin on the sides, as well as hydraulic upper deck, mobile compartment dividers and a non-skid rubber surface on the floor and a sprinkling equipment (Christensen and Barton-Gade, 1996). A survey in Spain showed that all trucks had uncovered sides and especially during winter pigs were less stressed (lower blood cortisol levels) when transported at high densities ($< 0.40\ m^2$/pig) as they coped better with cold stress by huddling (Oliver *et al.*, 1996). The sides and ceiling must be insulated and light reflecting in order to not expose pigs to hot surfaces in summer and cold surfaces in winter. In a recent Danish survey, the highest mortality rate reportedly occurred in dark-coloured vehicles without forced ventilation and with internal ramps for loading pigs onto the upper deck (Barton-Gade *et al.*, 2005). Internal ramps are a feature of the large punch-hole trailers (often pot-belly models; Figure 2) holding more than 200 pigs which are popular in North America and which are considered an important factor in the transit losses increase (up to 0.22% in 2002) recorded in the US since 1990 (Zanella and Duran, 2001).

Beside having restrictions in the ventilation system, triple deckers, which are frequently used in Italy, Spain, Holland and Belgium, make difficult the practice of off-loading as the height between the decks is often only 90 cm and pigs have to be forced in some way (goading and kicks) to leave the truck (Christensen *et al.*, 1994). The availability of a mobile second deck could be a solution as it can be raised slightly to allow the handler to crawl into the lower deck and off-load the animals (Christensen *et al.*, 1994). The ideal truck for pig transport is a two-decked type since these vehicles have a deck height such that the handler can enter and off-load without stressing the pigs.

Very little work has been done on the effects of truck type on pork quality and in these few studies only two-decked vehicles were used. Ludtke *et al.* (2004) found no difference in pork quality between pigs transported in a modern truck equipped with movable deck and misting system and those hauled in a traditional vehicle with fixed decks and adjustable loading ramp. Similarly, Dalla Costa *et al.* (2007) reported

Figure 2. The pot-belly trailer is criticised for its difficulties in loading and unloading (Photo courtesy of Luigi Faucitano).

no effect on pork quality when comparing a single-decked with a double-decked truck. However, Lynch *et al.* (1998) reported lower pH values and paler color in pork from pigs transported in a traditional wooden trailer equipped with internal ramps compared to those hauled in a modern truck having two floating hydraulic decks and air suspension.

The floor type is also important for the comfort of pigs during transport. The most recommended material is lightweight rubber (Christensen and Barton-Gade, 1996) given its anti-skid and anti-noise properties. Furthermore, when compared to aluminium and iron flooring, the floor of rough rubber texture seems to reduce the incidence of PSE pork by 1.5% because of its good insulating properties (Guàrdia *et al.*, 2004). Straw or deep, dry shavings should be used to cover the deck floor at temperatures below 10 °C to maintain the pig body temperature and normal heart rate (Schutte *et al.*, 1996). Cold stress, in fact, can lead to death during transit (Clark, 1979) and to meat quality losses due to extra-trimming (Berg, 1999). When temperatures exceed 20 °C, straw-bedding must be avoided to prevent the risk of heat stress (showed by increased heart rate) and replaced by wet sand or shavings to keep pigs cool (Schutte *et al.*, 1996; Warriss, 1996).

4.2. Temperature and ventilation

The temperatures encountered by pigs during transit can vary up to approximately 20 °C. This variation in temperature within the vehicle is related to variation in temperature outside and to the amount of water and heat produced by pigs during transport (Lambooij, 1988; Kettlewell *et al.*, 2001). Given that the thermoneutral zone for pigs is 26-31°C, the air temperature should not exceed 30 °C (Randall, 1993). Particular attention must be paid to the upper deck transport environment as the temperature can be up to 6 °C higher compared to the lower deck when outside temperatures range from 12 to 6 °C (Christensen and Barton-Gade, 1996). It is known that cold stress during transport and/or lairage leads to higher incidences of DFD meat due to higher energy demand to maintain body temperature (Gallwey and Tarrant, 1978). Due to the same reason, Gispert *et al.* (2000) also found higher levels of blood cortisol in pigs subjected to winter transports. On the other hand, heat stress leads to higher lactate accumulation in the muscle blood flow resulting in higher incidence of PSE meat (Honkavaara, 1989a,b).

When the vehicle is in motion, ventilation is not compromised, provided ventilation openings are sufficiently large and go along the whole length of the vehicle at the pig height. However, Christensen and Barton-Gade (1999) failed to find significant effect of 150 and 350 mm ventilation openings at varying deck heights (90 to 130 cm) on the lower deck on internal temperatures in the vehicle or on heart rate in pigs, when the vehicle was in motion. Whereas, Chevillon *et al.* (2004) recommends openings of 40 cm in hot weather condition to ensure a good ventilation (300 m^3/h of air flow per pig) inside the truck. In cold weather the openings should be partially or fully closed reducing the air flow to one third (113 m^3/h of air flow per pig).

Effective mechanical/forced ventilation is credited with reducing deaths in the truck (Nielsen, 1982). This form of ventilation is particularly recommended in stationary vehicles and when deck heights are low. A forced ventilation with a capacity of 75 m^3 per pig (120 pigs in all) during transport at temperatures of 20 °C, combined with an intermittent misting system at temperatures of 25 °C, resulted in a low transport mortality (0.012%) (Christensen and Barton-Gade, 1999). Indeed, spraying pigs for 5 minutes at the end of loading reduces body temperature by 10%, and because of that it is recommended when the outside temperature is ≥10-15 °C (Chevillon, 1998).

The height of the compartment should be adjusted to the type of ventilation. According to the latest recommendations of the Scientific Committee on Animal Health and Animal Welfare of the European Commission (SCAHAW, 2002), the height of the compartment should be 15 cm above the highest point on the animal in vehicles with efficient forced ventilation and 30 cm above the highest point on the animals in vehicles with natural ventilation. Hence, three deck vehicles are only allowable if equipped with forced ventilation.

4.3. Noise and vibrations

The noise and vibration associated with transport have been demonstrated to be aversive to pigs. Exposure of pigs to simulated transport (noise and vibration) led to an increase in plasma vasopressin, which is an indicator of travel sickness (Forsling *et al.*, 1984). Stephens *et al.* (1985) taught pigs to press a switch panel to turn off a transport simulator which produced vibration and noise. All pigs responded behaviourally to terminate the simulator. When the vibration component was switched off the pigs continued to make the response to switch the noise component off, though with a lower frequency. An increased heart rate during transport compared to previous resting levels has been described by various authors (Stephens and Rader, 1982; Villé *et al.*, 1993; Perremans *et al.*, 1998). Geverink *et al.* (1998a) showed that pigs that were loaded on the lorry and transported for 25 minutes on a relative 'rough' journey (i.e. on minor roads) had a significantly higher heart rate and cortisol levels than pigs that were loaded on the lorry which subsequently remained stationary for 25 minutes. In addition, during the post-transport period the transported pigs displayed less exploratory behaviours and spent more time lying, while their heart rate was lower than that of pigs from the stationary lorry. This shows that transportation exhausts the animals for a prolonged period.

Journeys should be as 'smooth' as possible, which implies careful driving on motorways. Vibration can also be reduced by a good air suspension on all axles of the lorry (Randall *et al.*, 1996). Research by Perremans *et al.* (1998) gives indications for maximum acceleration and frequency ranges of vibration in the vertical direction resulting in the least change in heart rate and stress hormones (cortisol and β-endorphin).

5. Non-ambulatory animals or those otherwise unfit for transport

In Canada, the Recommended Code of Practice for the Care and Handling of Farm Animals -Transport (CARC, 2001) recommends that all animals be in good physical condition and optimum health prior to loading. This is true in many other countries as well (CEC, 2005; Chevillon, 2005). Animals that are sick, injured, disabled, fatigued or cannot be moved without causing them additional suffering are unfit for transport. These animals are known as compromised. Non-ambulatory animals – any animal that due to age, injury, metabolic or systemic disease, etc., is unable to stand or walk without assistance – are one class of compromised animals. In Ontario, non-ambulatory animals require a veterinary certificate before they can be transported to slaughter. Non-ambulatory certificates are required in many countries, so all pig producers and transporters should be familiar with such documents. Without a veterinary certificate, compromised animals must remain on-farm for treatment. Non-ambulatory pigs should always be moved using approved and humane methods. Where such methods are not available or appropriate, animals should be euthanised on-farm.

5.1. Proper handling and care during transport

The keys to dealing with non-ambulatory animals are prevention, preparation and prompt action. Injuries leading to animals becoming non-ambulatory can be reduced through proper training of barn staff and adherence to a zero-tolerance policy for the mishandling of animals. For example, a lightweight plastic board and a canvas 'slapper' should be used instead of electric goads or prods. Slappers are used to make noise by hitting a nearby board or fence and thus, avoid hitting the animal and reducing the need for excessive noise or shouting. As a result, pigs will remain calm and be easier to handle compared with excited pigs which tend to bunch together and can be harder to sort. Injuries while loading animals onto the transport vehicle can further be reduced through the provision of non-slip floors and properly designed loading ramps.

In the event that an animal becomes non-ambulatory, producers and barn staff need to be prepared to promptly deal with the animal. Clearly defined policies and procedures need to be in place and communicated to staff. A decision must be made quickly to either euthanise the animal on-farm or to call a veterinarian in order that a non-ambulatory certificate can be filled out. Pigs that have been chronically ill and that have recently been treated with antibiotics or pigs that are in extreme distress should be humanely euthanised on-farm. By following recommended procedures, and using approved methods and proper equipment, it is possible to handle non-ambulatory animals in a humane manner.

With a veterinary certificate, non-ambulatory pigs should be moved as soon as possible to the nearest slaughter facility. Various carts are available for humanely moving non-ambulatory hogs, or producers may chose to use a transport service that has the vehicles and equipment required for properly handling non-ambulatory animals. Dragging a non-ambulatory animal by its head or limbs is illegal except in emergencies. Approved methods for moving non-ambulatory animals include the use of: (1) Slide boards and mats in which non-ambulatory animals are gently rolled onto a board and moved by attaching a rope, chain or cable to the board which is then dragged using either a tractor or a winch, (2) Front-end loaders with a bucket of adequate size to accommodate the animal or skid steer loader (bobcat) is adequate for small animals such as pigs and requires two people, (3) Hand carts in which small non-ambulatory pigs can easily be moved, and (4) Specialised equipment (such as slings) which are specially designed for moving non-ambulatory animals provided they are used in accordance with the manufacturer's recommendations.

5.2. International regulations/guidelines and state of the art

5.2.1. Non-ambulatory pigs

A survey was conducted by the Canadian Food Inspection Agency (CFIA) on market hogs and cull sows, which concentrated on 35 inspection sites across Canada, representing 22 slaughter facilities and 13 auction markets and assembly facilities (Canada Gazette, 2004). Over a period of two months in 2003, a total of 3,433,823 hogs and sows were inspected, of which 4,684 were observed to be non-ambulatory on arrival at the packing plant (322 sows and 4,362 market hogs). After inspection, 1,284 of all non-ambulatory animals had to be fully condemned (47 sows, 1,237 market hogs). Of the non-ambulatory animals, 1,508 carcasses were partially condemned (49 sows, 1,459 market hogs). This means 60% of non-ambulatory pigs arriving at these facilities resulted in carcasses that had to be at least partially condemned. The data submitted also indicated that the pigs became non-ambulatory in almost equal numbers on the farm and during transit. On the farm, 1,547 market hogs and 117 sows were non-ambulatory. In assembly yards, 32 market hogs and 2 sows were found to have become non-ambulatory. During transportation, 1,236 market hogs and 136 sows were found to have become non-ambulatory (Canada Gazette, 2004).

Similarly, in a more recent study out of the United States involving 12,511 pigs at the University of Illinois, 0.26% of pigs were deemed non-ambulatory on-farm, 0.23% of pigs were dead on arrival at the packing plant, and 0.85% of pigs were non-ambulatory upon arrival (Ritter *et al.*, 2006). Investigating the affect of space allowance on the incidence of non-ambulatory animals during transport, Ritter and colleagues reported that increasing the amount of floor space per pig from 0.39 to 0.48 m^2 reduced the percentage of total non-ambulatory pigs (0.52 vs. 0.15%, respectively) and total losses (dead and non-ambulatory pigs) at the plant (0.88 vs. 0.36%, respectively). However, it should be noted that loading density did not affect the percentage of non-ambulatory or injured pigs that arrived at the plant.

Slaughter plants have no interest in dealing with animals that should not have entered marketing channels in the first place. In Canada, a growing number of federal and provincial slaughter plants are refusing to handle 'downners'. In fact, several federal plants now charge a small fee to put these animals down. The marketing of livestock compromised by disease or injury: (1) degrades the welfare of the animal, (2) is an economic burden to the producer, the transporter, and the processor, (3) damages the prestige of the livestock production industry, and (4) potentially endangers public health. However, most producers that ship non-ambulatory livestock do so because they see no alternative be it due to provincial restrictions, lack of inspectors, or missing infrastructure. As a result, countries such as Canada have encouraged those within the veterinary profession to educate producers on the prevention, proper care, handling, and humane disposition of non-ambulatory animals.

5.2.2. Early-weaned or Iso-Wean piglets

Iso-weaning is defined as a practice in which piglets are weaned from their mothers earlier than the normal weaning period of approximately 28 days (CARC, 2001). Piglets are separated (weaned) early from the sow so contact and exposure to disease is kept to a minimum. In Canada, a maximum group size of 50 is recommended for Iso-weaned (segregated early-weaned) piglets in transit (CARC, 2001), primarily to minimise the time assembling and unloading each group. Well organised systems may facilitate the assembly and loading of up to 100 Iso-weaned piglets in a group. Similarly, the 1983 version of the Australian Model Code of Practice for the Land Transportation of Animals (PISC, 1983) and the Code of Recommendations and Minimum Standards for the Welfare of Animals Transported within New Zealand (AWAC, 1994), recommend young piglets, sows with piglets, adult boars, unfamiliar groups of pigs, and sows in advanced pregnancy were to be transported separately. However, best practice standards for loading density in transporting very young (e.g. early weaned or iso-wean pigs) has not been researched to any great length and is an area that needs to be investigated further in anticipation of global pig transport standards.

Furthermore, a review of the recommended times (journey durations) for very young pigs is warranted. In Canada, current transport welfare standards state that feed, water and rest are to be provided more often for animals with reduced ability to cope with the stress of transport, such as very young or old animals, and for all animals that are transported under adverse conditions, such as travel through different climatic zones and weather extremes (CARC, 2001). Nursing animals accompanying their dams are to be allowed an opportunity to nurse undisturbed at suitable intervals. Furthermore, nursing young are to be provided with appropriate additional feed and water at least every 8 hours. In contrast, Australia's Model Code of practice for the Welfare of Animals (SCAHAW, 2002) does not provide any set maximum journey duration for pigs. Rather, it stresses the total time pigs have been deprived of food and water prior to loading. While market weight pigs are to be fed and watered at least once in each 24 hour period and preferably twice, young animals, especially piglets, require more frequent feeding and watering during transport.

In a study of piglets early-weaned at 17 ± 1 day-of-age, Lewis and Berry (2006) reported that young pigs transported by van spend an average of 75.6% of the time in transit lying, while standing behaviour occupied 21.6% of the time. Furthermore, as transit time increased, the percentage of time early-weaned pigs spent active significantly decreased, while lying time increased. More specifically, Lewis and Berry (2006) found that within the first 12 h of transport, standing averaged 36% of the piglets' time, while resting accounted for 60% of the time. During the second 12 h of transport, lying time increased to 91.5% of transit time, while standing time dropped to only 7.4%. Lewis and Berry (2006) speculated that some reasons for the increase in lying behaviour may have been associated with either fatigue (Lambooij *et al.*, 1985) or huddling behaviour. The authors also reported sitting behaviour was more common during the first 12 h of transport (2.8 %) than during the second 12 h of transport (0.3%). Dybkjær *et al.* (1992) has described sitting behaviour in pigs as an indicator of stress. Fighting behaviour, another indication of transport stress, was infrequent during the first 6 h of transport (Lewis and Berry, 2006), however the number of pigs fighting increased significantly during the summer versus the winter, which the authors suggest may have been indicative that establishment of the dominance hierarchy may have been reduced or suspended in the colder transport environment. The findings of Lewis and Berry (2006) suggest that early-weaned pigs may become habituated to some elements of the transport environment better than market weight hogs.

In an earlier study on food and water withdrawal in early-weaned pigs, Berry and Lewis (2001) reported an increase in weight loss and dehydration which increase the physiological stress these young animals experience in transit. Specifically, piglets used in a 24 h simulated transport model had higher hematocrit levels (41.1%) than control pigs (39%), indicative of dehydration which needed to be attenuated post-transport. However, the authors concluded overall that young piglets are only able to recover and perform adequately in the early post-weaning period if extremes of transport duration and temperature are avoided. Otherwise, the effect of even simulated transport in such animals was still measurable for up to 7 days post-transport, indicating the young animals had difficulty recovering from the experience almost a week later.

Temperature and season also has been shown to have an effect on the welfare of early-weaned pigs (Lewis *et al.*, 2005). While animals can huddle to keep warm and bedding material can be provided during winter transport, high temperatures encountered during the summer, particularly if adequate ventilation is not provided, can prove to be fatal. Lewis *et al.* (2005) measured skin temperature at the surface of the ear in early-weaned pigs during transit and found temperatures were significantly higher during the summer (36.2 °C) than during spring/fall (27.0 °C) or winter (23.1 °C). Rectal temperatures were also reported to be higher during the summer (39.2 °C) compared with fall (38.7 °C) and winter (38.6 °C). Based on these findings, Lewis and colleagues concluded that temperature is a significant factor affecting the welfare of early-weaned pigs during transport.

5.2.3. Cull sows and boars

The trend toward centralisation of slaughter plants into fewer, larger facilities and the international movement of slaughter animals will continue to provide challenges for the humane transportation of animals, as the average slaughter pig will need to travel longer distances to slaughter. For example, in western Canada, cull sows and boars are primarily exported to the United States, where facilities are available to slaughter this class of animal (Whiting and Brandt, 2002).

Whiting and Brandt (2002) discussed the use of adapted loading density equations to determine the space allowance of cull sows and boars in transport, based on commercial applications in Manitoba, Canada. In the study, the authors noted how truckers perception of the needs of the pigs was the primary determinant of reasonable maximal loading pressure (Figure 3). Animal transporters were comfortable loading 50 to 150 kg pigs at floor pressure levels that would allow for standing room only, for short trips. However, the same animal transporters would consistently allow weaned pigs, unthrifty pigs, and cull sows space to lie down, as it is a perceived need of the class of animal. One possible explanation provided for the additional space given to cull breeding swine is that the latter are very uniform in size and body condition and may represent an optimum physiologic state. As breeding swine age, a wide range of mature body size and body condition develops, presenting as a non-uniform load by the time they are transported as cull sows and boars. Cull breeding swine may also

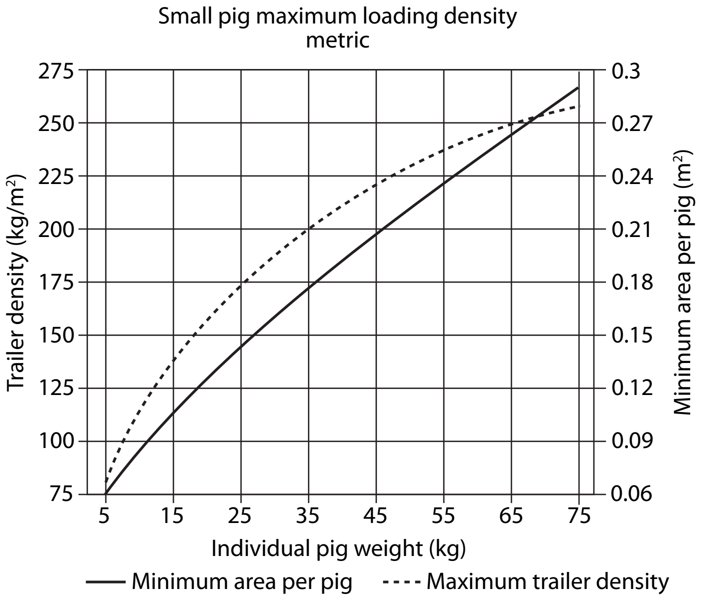

Figure 3. Minimum space allowance for young and cull swine in transit based on average individual body weight (Metric). The top line describes maximum trailer carrying capacity (left hand axis); minimum space per animal is the bottom line and right hand axis. Reduce load by 25% in hot humid weather. Thin animals require more space than a finished animal of the same weight (CARC, 2001).

have an increase in lameness and a decrease in general ambulatory ability, which requires more room to get up and down. These physiological realities result in cull animals needing more space on a unit weight basis than do the same animals at the peak of youth, as represented by market weight (Whiting and Brandt, 2002). Sows should be marketed when they are still fit for travel and it is advised that sows and pigs unable to walk should be euthanised on the farm. Pigs which have temporarily become non-ambulatory due to stress must be allowed to recover before they are put on a truck. Temple Grandin, a leader in the area of livestock handling and a faculty member at Colorado State University, emphasises the need for producers to select sound animals with good feet and legs since sows and boars can become lame and non-ambulatory in transport as a result of poor leg conformation (Grandin, 2000).

A combination of environmental factors and poor management has resulted in increased sow mortality (Koketsu, 2000). Koketsu (2000) collected data from 825 U.S. and 240 Canadian farms and found the highest mortality rates correlated with the largest farms. Loula (2000) has suggested that staff at large farms are not always properly trained to recognise when an animal is losing weight or getting sick. The decline in sow condition on large farms may increase the number of unfit sows which are transported and lend itself to two-tier sow marketing systems (Grandin, 2000).

6. Conclusions

Current density guidelines need to clarify the term overcrowding in order to allow for comparisons between current recommended practices and scientific results. However, until there is some debate as to whether animals in transport need to be able to lie down, or to simply stand no recommendation or guideline can be given yet.

There is currently no information contained within most international pig transport standards on the appropriate minimum space allowance in transport for non-market weight pigs, such as iso-wean piglets, young feeder pigs, underweight slaughter pigs, replacement gilts, and cull boars and sows. Likewise, very little scientific research has been done to determine such standards for this class of animals. Most studies have investigated loading densities in pigs of slaughter weight (90-110 kg). As such, more research needs to be done to determine the appropriate loading densities of very small (i.e. early-weaned) and very large (ie. cull pigs being transported) animals. The effect of extremely hot and extremely cold conditions during transport and its interactive effects with loading density also requires greater study. This is of particular importance in countries in which transported pigs encounter extremes in temperature throughout the country and over the course of a year. Cull breeding animals is one of the most serious problem areas. Some of these animals are too weak for travel and producers need to market their animals when they are still fit for travel. The development of auditing systems for monitoring breeding animal condition and the development of markets to further increase the value of cull breeding stock will help improve the fitness of pigs for transport and will require accountability for losses throughout the marketing chain.

Recommendations to allow the long-haul transport of pigs only under superior conditions are reflected in current EU guidelines in which transport duration limits are determined by the type of vehicle and whether it is 'basic' or 'higher standard'. Similar guidelines may be advisable in other countries to enable transporters to haul animals short distances (e.g. 8 hours or less) without food or water in 'basic' transport vehicles, however for longer transport durations (e.g. up to 24 hours) pigs must be transported on 'higher standard' vehicles in which water is available at all times. However, it should be noted that the scientific literature also indicates that short duration transports are perceived as extremely stressful in pigs, and every effort to attenuate such stress during short transport journeys should be made.

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Chapter 7. Effects of preslaughter handling on stress response and meat quality in pigs

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Abstract

At all times prior to slaughter pigs may experience stress from a range of handling practices, such as fasting, loading and transport, mixing and human coercions. Preslaughter stress is both an animal welfare issue and a meat quality issue. On one hand, behavioural and physiological studies revealed that many of these handling practices are adversive to pigs and that animal well-being can be affected detrimentally. On the other hand, poor handling throughout the preslaughter period can also lead to carcass depreciation and meat quality defects (PSE and DFD) which are reflected in great economic losses for the industry.

Keywords: pigs, ante-mortem handling, stress, meat quality

1. Introduction

Increased public concern for the welfare of farm animals has led to a decline in the consumption of pork in a number of industrialised countries. In a survey conducted in Australia among adolescent women, it came up that the image they usually associate with meat or meat eating is mostly animal cruelty (Worsley and Skrzypiec, 1997). In a similar survey conducted in Western Canada among 18-50 years old women, many of them declared to be concerned about killing animals or the treatments of animals being raised for food (Chapman and Barr, 2000). In a very recent survey involving 25,0000 consumers from the 25 European Union member states, it appeared that 57% consumers were willing to pay a little more for pork sourced from an animal welfare friendly system (EC, 2005). Likewise, most consumers interviewed in a survey run in Northern Europe (France, UK, Denmark and Sweden) showed to accept a price increase for pork from pigs raised outdoors than from pigs raised conventionnally (Dransfield, 2004).

In response to the pressure of the media and the consumer organisations several meat and supermarket companies (i.e. Freedom Foods) adopted market strategies to create the image that they care for their customers. This caring attitude is translated in marketing safer, healthier and welfare friendly-products (i.e. green label) as well as in imposing welfare standards on suppliers as a part of their contractual relationship.

Additionally, the producers and the packers have increased their efforts in improving the pre-slaughter and slaughter procedures in order to prevent economic losses. Indeed, death losses during and after transport for slaughter at Canadian abattoirs which have been estimated to be approximately 0.1% of pigs shipped corresponds to approximately 1.5 million kg of pork lost per year (Murray, 2001). A severely blemished carcass can be downgraded up to a 6% of its total value (MLC, 1985) and a severely bruised bacon or ham can be depreciated to 1/5 of its normal value (Chevillon and Le Jossec, 1996). Preslaughter stress-induced meat quality problems, such as PSE (pale, soft, exudative) and DFD (dark, firm, dry) pork, produce greater losses (Scott and Schaefer, 1999). In pigs, PSE defect leads to shrink losses which cost the plant about $5/carcass (Murray, 2001) and can lead to up to 40% unsaleable product (Grandin, 1993). According to Hambrecht *et al.* (2004), the effect of inadequate preslaughter handling on PSE pork incidence is so great that even the most advanced carcass chilling technology cannot compensate.

The responsibilities for the occurrence of profit losses from farm to slaughter are equally shared by the producer and the abattoir. On one hand, the producer must guarantee proper selection, care, and handling to the point of delivery to the abattoir. Pigs showing bruises on the body at the time of loading should be kept on farm until the haematoma is re-absorbed (Faucitano, 2001). On the other hand, the abattoir is responsible for the optimisation of the lairage conditions (abattoir layout, handling systems, etc.) in order to maintain the welfare state of pigs as acceptable as possible and to ensure optimal, consistent and uniform carcass and meat quality.

In view of the above, it seems to be in everybody's interest to improve preslaughter handling methods and facilities in order to improve welfare and save the pig industry money by reducing aberrant meat quality. As Duncan and Fraser (1997) pointed out, science cannot provide a purely objective measurement of welfare because the conclusions we draw about an animal's welfare are based on value judgements as well as knowledge. However, welfare can be assessed by using a large number of variables (Broom and Johnson, 1993). Frequently used welfare indicators for preslaughter treatment are behavioural and physiological (heart rate, hormones, and body temperature) responses (Schaefer *et al.*, 2001). These responses to preslaughter treatment are not only indicators of welfare, but may also have an effect on perimortem muscle metabolism and thereby on meat quality (see Chapter 2). Hence, in this chapter, the term 'meat quality' does not refer to quality properties of meat for human consumption, but will be used as an indicator of the muscle physiology response to preslaughter stressors. Indeed, sympathetic arousal and adrenaline release can trigger a rapid glycogenolysis and excessive lactate production, thus favouring the development of PSE (Tarrant, 1992). On the other hand, the relationship between cortisol and meat quality parameters is conflicting (Cassens *et al.*, 1975) and there may be an absence of aberrant meat quality in pigs with high cortisol levels (Gregory *et al.*, 1987). This discrepancy might depend on the different reaction to physical and psychological stressors of muscles differing in muscle fibre contractile properties, being the glycolytic muscles more prone to develop PSE pork and the oxidative ones to develop DFD pork (Hambrecht *et al.*, 2005). However, because the hypothalamic-pituitary-adrenal (HPA) axis and the sympatho-adrenal axis influence each other, increased HPA-axis activity can stimulate adrenaline release. Indeed, increased cortisol and creatine phospho-kinase (CPK) levels in blood have been clearly associated with higher ultimate pH values (DFD) (Warriss, 1996b; Gispert *et al.*, 2000).

2. Critical points within the pre-slaughter period

During preslaughter treatment pigs are exposed to various factors that may be detrimental to welfare and subsequent meat quality. These potential stressors range from separation from the familiar environment of the farm pen, to the process of loading, unloading and transport, the design of lairage, and treatment by handlers. Adequate handling methods and facilities at all preslaughter stages are required to guarantee animal welfare.

2.1. Housing conditions at the farm

During the fattening period, slaughter pigs are usually kept in the same pen under intensive housing conditions. This is often attended with little environmental variation and low levels of stimulation. As a result pigs may have little capacity to adapt to novel stimuli or new environments (Broom and Johnson, 1993), show a high degree of reactivity to novel stimuli and in some cases may be very disturbed by them (Stolba and Wood-Gush, 1980). Another aspect of routine husbandry is that the only contact pigs have with humans is usually unpleasant, e.g. cutting teeth, tail docking, castration for the males and vaccinations. Hemsworth *et al.* (1994) showed that the behavioural response of commercial pigs to one handler is likely to extend to other humans. These factors can result in pigs being very aroused by novel stimuli such as those commonly encountered before slaughter e.g. loading, unloading, transport, driving by unfamiliar stockmen at the abattoir, and mixing with other unfamiliar pigs (Kilgour and Dalton, 1984). The way pigs react to preslaughter conditions and the effects of these conditons on their welfare and meat quality also depend on their genetic background (review by Terlow, 2005; Chapters 2 and 9). All these aspects explain the variation of the behavioural and physiological response to preslaughter stressors and resultant meat quality reported in pigs proceeding from different farms or raising systems (Tarrant, 1989; Troeger, 1989; Stephens and Perry, 1990). For example, the farm was the major contributor (55% vs. 25% and 19% for the plant and transporter, respectively) to the 8,000 dead pigs on arrival (DOA) per year reported in a Eastern Canadian transport survey (Dewey *et al.*, 2004). Within this incidence, a large variation between producers was also reported with 10% of the producers loosing at least 0.4% of their pigs (Dewey *et al.*, 2004). Furthermore, the raising system (outdoors vs. indoors) can have an impact on the behavioural response of pigs to preslaughter handling, pigs sourced from outdoors or free range system being less aggressive and active during transport and lairage than conventionally raised pigs (Hunter *et al.*, 1997; Barton-Gade, 2004).

2.2. Pre-transport handling at the production site

The effects of the producer is not only limited to pre-slaughter losses associated to pigs that die during transport or in lairage as reported in the Ontario survey by Dewey *et al.* (2004), but also of those that arrive at the plant unable to walk normally if at all (Ellis and Ritter, 2006). The largest proportion of these animals is referred to as non-ambulatory, non-injured (NANI) pigs. NANI pigs are a problem for producers and processors. In US plants approximately 0.5-1% of pigs has been characterised as NANI costing more than 10 million dollars/year for the producers (Carr *et al.*, 2005). In a survey of the Canadian Food Inspection Agency on a population of more than 3 million pigs, 4,700 pigs were observed to be non-ambulatory on arrival at the slaughter plant. It was also reported that 6 out of 10 non-ambulatory animals at the plant were not wholly passed for human consumption (Appelt, 2003). The major cause of this full or partial condemnation is due to unacceptable amount of residual blood in the carcass due to poor bleeding (J.A. Correa, F. Ménard Inc., Canada, personal communication). The effect of the farm on these losses has been associated to poor preparation of pigs at the farm prior to loading and the pig response to handling at loading (Ellis and Ritter, 2006). The stressfulness of the loading procedure results from the combination of different factors, such as group splitting in the finishing pen, distance moved from the pen to the load point, group size, mixing, handling system (i.e. prodding) and eventually the design of the loading device (either ramp or quay). In large swine units, the load point is often far from the finishing pens so pigs are imposed to walk long distances to get to the load point resulting in muscle fatigue. A recent survey on 17,000 pigs showed that a long walking distance (> 60 m) from the pen to loading tended to increase the proportion of NANI pigs at the load point (Ellis and Ritter, 2006). The solution to this problem may be represented by the indirect transfer of pigs from the home pen to the truck through the lairage landing pen system (Chevillon, 2005; Figure 1). This system, which is recommended in France, reduces the time required to load

Figure 1. Landing lairage pens for pigs at the farm (Photo courtesy of P. Chevillon, IFIP, France).

100 pigs from 50 to 20 min and decreases the transport mortality by 25% as pigs are less stressed (Chevillon, 2005). The system consists of small pens to keep pigs in the original group until loading takes place and thus avoid fighting amongst animals to occur. The recommendations for stocking density in these pens are based on the length of lairage time (SCAHAW, 2002). The Danish industry for space requirements for these areas for slaughter pigs weighing up to 110 kg are:

- 0.45 m^2 per pig for holding periods below 30 minutes;
- 0.55 m^2 per pig for holding period up to 3 hours;
- 0.65 m^2 per pig for longer holding periods.

2.2.1. Fasting and dehydration

One of the rules included in many codes of practice and legislations is that pigs should be fasted before slaughter at reasonable intervals and given water *ad libitum* (AAFC, 1993; SCAHAW, 2002). Fasting decreases the mortality rate and prevents pigs from vomiting in transit, improves the food safety as it prevents the release and spread of bacterial contamination (*Salmonella*) through the faeces within the transport group and through the spillage of gut contents during carcass evisceration, increases the ease and speed of the evisceration procedure and helps reduce the environmental pollution through a lower waste disposal volume (gut contents) at the abattoir.

Currently, a feed withdrawal of 16-24 h before slaughter is recommended in practice (Eikelenboom *et al.*, 1991). However, the recommendations vary a lot according to the country. In France, a 7-14 h fasting before transport and 24 h total fasting before slaughter is considered ideal to get empty stomachs (< 1.4 kg) at the evisceration stage and to improve meat quality (Chevillon *et al.*, 2006a,b). Indeed, the application of a 12-18 h on farm significantly decreased the total mortality rate (transport + lairage) in several Spanish abattoirs (Guàrdia *et al.*, 1996) (Table 1). In UK, a total fasting time of 8 to 18 h has been suggested to reduce carcass yields losses to a minimum, to prevent pigs vomiting during transport (travel sickness) and to avoid problems of hygiene during carcass dressing (Warriss, 1994). In Canada, on farm fasting of more than 5 h is recommended unless the trip would exceed 24 h (AAFC, 1993). However, many producers are still reluctant to follow this practice due to lack of adequate facilities or the concern about the carcass weight losses. Indeed, a 24 h-fasted pigs can loose 5-6% of this weight (1-2% carcass weight), but these losses proved to be insignificant in terms of carcass weight (Beattie *et al.*, 1999; Brown *et al.*, 1999a,b). Jesse *et al.* (1990) concluded that as long as pigs are not mixed (only one farm of origin) they can cope with the stress of fasting and being transported long distances (e.g. 563 km) without any extended detrimental effects on subsequent health and performance. Whereas, feeding pigs until transport is even more costly as the feed given in the last 10 h will not be converted to carcass gain and thus will be wasted.

Inadequate preslaughter fasting can have detrimental effects on muscle physiology and eventually on meat quality. Maribo (1994) recorded increased muscle acidification in the loin muscle of pigs which were not fasted and were sent to slaughter immediately after the arrival at the abattoir. Long fasting periods, when associated to long transports or lairages, would tend to decrease the incidence of PSE meat and increase the prevalence of DFD meat due to muscle glycogen exhaustion, especially in those

Table 1. Mortality rates (%) during transport and lairage and total mortality in relation to on farm fasting period in some Spanish abattoirs (modified from Guárdia et al.*, 1996).*

	Fasting time				
	< 12 h	12-18 h	> 18 h	SEM	P
Mortality in transport	0.82	0.00	1.95	0.25	***
Mortality in lairage	0.78	0.26	0.82	0.12	**
Total mortality	0.75	0.00	0.29	0.42	**

(p< 0.01); * (p< 0.001).

muscles supporting the animal's posture and weight (i.e. *Adductor* and *Semispinalis capitis*) (Eikelenboom *et al.*, 1991). The application of a 20 h on farm fasting time in the winter period contributed to the highest DFD incidence (19.8%) recorded in the survey at Spanish abattoirs (Gispert *et al.*, 2000). However, a number of other studies (De Smet *et al.*, 1996; Beattie *et al.*, 2002; Murray *et al.* 2001; Morrow *et al.*, 2002) reported no or very little impact of feed withdrawal on meat quality. When fasting is not complicated by other preslaughter practices (i.e. mixing, long transport or lairage) muscle glycogen does not deplete to such an extent that pork quality is influenced negatively (Faucitano *et al.*, 2006).

A likely drawback of feed restriction prior to slaughter is the increased aggressiveness, especially after mixing (Brown *et al.*, 1999b; Turgeon and Bergeron, 2000). Luescher *et al.* (1990) showed in their study that the state of excitement of pigs at the time of mixing may affect their subsequent aggressive behaviour, and that treatments, which appeared to cause the pigs to become most excited and aroused (such as fasting), led to the highest levels of fighting.

It seems that fed pigs take some rest between bouts, whereas fasted pigs keep fighting for longer (Fernandez *et al.*, 1995). In a British study, pigs deprived of food for more than one hour had the carcasses with a higher incidence of severe skin damage due to progressive fighting (Brown *et al.* 1999b). However, it was also reported a higher easiness of handling when pigs are fasted (Eikelenboom *et al.*, 1991).

With the possible exception of restricting pigs from water for a few hours before transport in order to avoid motion sickness (Randall and Bradshaw, 1998), water must be provided to animals both before and following transportation (AAFC, 1993). To date, there is no scientific evidence supporting the recommandation to provide pigs with water through the whole ante mortem period (from the farm gate until slaughter). As already mentioned in Chapter 6, water consumption is low during long distance transportation. A reason for the low water consumption during transport may be that even thirsty pigs do not drink from a nipple when the vehicle is moving. Water should therefore be offered during stops, especially when the temperature is above 20 °C, and not later than 8 hours after the start of the journey (Brown *et al.*, 1999a; SCAHAW, 2002).

Feeding nutrient-rich diets before periods of stress and nutrient deprivation proved to increase nutrient retention in tissue stores preventing dehydration, energy depletion, ion depletion and accelerated protein catabolism which have adverse effects on animal welfare and meat quality (Schaefer *et al.*, 2001).

The administration of oral electrolytes (particularly sodium bicarbonate) in the last few days prior to slaughter proved to maintain a normal acid-base balance of the animal, i.e. the balance between the total positive charges (mainly potassium, sodium, calcium, and magnesium) and the total negative charges (organic anions, phosphates, chloride, and bicarbonate), but showed to lead to moderate improvements in meat texture and pH fall rate (Ahn *et al.*, 1992; Boles *et al.*, 1994). Dietary magnesium supplementation proved to be effective in reducing the release of stress hormones (cortisol and cathecolamines) and glycogen depletion in the muscle (Kietzmann and Jablonski, 1985; D'Souza *et al.*, 1999). Several studies carried out in Australia (D'Souza *et al.*, 1998, 1999, 2000) showed that feeding 20 g magnesium aspartate (MgAsp) for 2 days prior to slaughter significantly improved pork quality and reduced the incidence of PSE meat also in pigs subjected to severe stress (mixing and repeated electrical prodding). More recently, Hamilton *et al.* (2003) reported an improvement in colour and water-holding capacity of pork by feeding 1.6 g of dietary magnesium the last day before slaughter. Another nutrient which has the potential to moderate stress by reducing the release of brain serotonin levels is tryptophan (Leathwood, 1987). However, the results on the effects of this aminoacid on stress response and meat quality are still inconclusive. Several studies (Geesink *et al.*, 2004; Li *et al.*, 2006; Peeters *et al.*, 2006) did not find any effect of short-term feeding of tryptophan on the stress response and meat quality of pigs submitted to stressful situations (i.e. electric shock, transport and no rest before slaughter). On the contrary, Guzik *et al.* (2006) reported that tryptophan has a negative effect on meat quality and skin lesions on the carcass although it decreases plasma cortisol levels. Aggression among unfamiliar pigs only seems to decrease in pigs fed high (4 times higher than normal) tryptophan diets, but the easiness of handling at unloading or in stun raceway does not seem to be affected (Li *et al.*, 2006; Panella *et al.*, 2006). Alternatively, herbal medicine can be used as a more natural treatement for anxiety and stress (Duke, 2002). A study of the effects of the administration of *Valeriana officinalis L.* and *Passiflora incarnata L.* on animal response to transport stress and meat quality showed that on one side these herbs slightly reduced the heart rate of pigs subjected to vibrations during simulated transport, but on the other side increased the incidence of skin bruises on the carcass, without affecting meat quality though (Peeters *et al.*, 2004, 2006).

Anyway, single nutrient approach to increase the resistance to stress and improve quality can be only partially successful. Schaefer (1995) and Schaefer and Dubeski (1997) showed that provision of vitamins, mineral, and amino acid complexes (i.e. Nutri-Charge, US Patents 5505968 and 5726675) are more efficacious in preventing dehydration and energy depletion than providing any single nutrient alone.

2.2.2. Mixing unfamiliar pigs

There is abundant literature substantiating the fact that mixing pigs with unacquainted pen-mates induces high levels of aggression aiming at establishing a new social rank. Fighting leads to elevated concentrations of cortisol (Parrott and Misson, 1989; Tan and Shackleton, 1990), increased skin damage score on the carcass, especially in boars, and meat quality defects (Warriss and Brown, 1985; Warriss, 1996a). However, in practice, pigs are often mixed prior to loading in order to obtain groups of uniform weight and to adjust the group size to that of the truck compartments. Of the 90.4% groups mixed at loading during 20 shipments to Spanish abattoirs, 50.4% were mixed on farm prior to loading and the remaining 40% were mixed inside the truck deck compartment (Faucitano, 2001). Installation of mobile dividing gates on the truck deck is a practical solution to eliminate mixing since, besides keeping the groups separated, it helps to adjust compartment space to suitable group size, thus preventing aggressive behaviour during transportation.

If mixing is unavoidable, the recommendation is to mix pigs at loading rather than later on as they tend to fight less on a moving truck and have more time to rest after fighting (Warriss, 1996a). Earlier mixing would also limit the negative effect of this practice on meat quality as it allows pigs drop the body temperature.

2.2.3. Loading

Loading pigs onto the truck is considered the most critical stage of the transport stage as showed by the 110-130 increase in the heart beats compared to a pig at rest (Chevillon, 2001) because of the strong human-animal interaction and the change of environment. Indeed, the transfer from the familiar fattening pen to the novelty of the truck interior and the abattoir area combined with the strong physical activity induced by the coercion to walk through alleys or sloped ramps, make pigs nervous and not easy to handle.

Moving pigs in a group size larger than the farm alley is a common practice at loading (Lachance *et al.*, 2005). This practice is mistakenly considered effective to speed up the handling procedure. However, for easier handling and faster movement it is recommended to have a well designed loading quay (0.8 to 1.5 m wide) and to move small groups of pigs (Lachance *et al.*, 2005; Lewis and McGlone, 2006).

In order to avoid delays in the loading procedures, pigs should be encouraged to move forward by pushing the group from behind with boards. The use of electric goads must be very limited (shocks lasting < 2 sec) and that of sticks/hoses must be avoided given their detrimental effects on the pig physiological condition (higher heart rate and salivary cortisol level) and transport losses (NANI pigs), carcass bruises and meat quality (blood spots) (Brundige *et al.*, 1998; Benjamin *et al.*, 2001; Faucitano, 2001). Recent research showed that a shock with an electric prod is more aversive than inhaling 90% CO_2 (Jongman *et al.*, 2000). However, the use of these handling systems is quite common at this stage and it would basically reflect the poor truck design (ramp instead of lift) and the inexperience of the handlers (Faucitano, 2001). Studies on the transport stage show that the highest peaks in heart rate occurred during loading and unloading (Villé *et al.*, 1993, Geverink *et al.*, 1998). Major contributing factors to these peaks are most likely climbing and descending the ramp (Van Putten and Elshof, 1978) and being handled (Villé *et al.*, 1993). Loading and unloading also leads to markedly elevated cortisol concentrations (Bradshaw *et al.*, 1996; Geverink *et al.*, 1998). The use of the hydraulic tail-lifts or decks makes the pigs easier to handle, prevents the handlers from using coercion on them and reduces loading time (Brown *et al.*, 2005). Furthermore, the use of a lift or a floating deck for loading pigs onto transport vehicles has been shown to reduce transport mortality in stress-susceptible pigs (Devloo *et al.*, 1971; Riches *et al.*, 1996). The availability of trucks equipped with hydraulic tail-gate lift proved to increase the number of transport groups handled with boards (31%) and limited the use of goads and sticks to only 14% and 19%, respectively, of the groups loaded at Spanish farms (Faucitano, 2001). Recently, Brown *et al.* (2005) studied the response of pigs to a modular system in which pigs are loaded on level ground with containers placed close to the fattening pen. This method actually reduced loading time and decreased heart rate in pigs being loaded, but still imposes some small degree of stress onto the pigs as evidenced by the elevated cortisol level. However, if the ramp is necessary, like in the case the truck is not equipped with hydraulic lift or there is a height difference between the loading quay and the truck deck level, it should have an angle of < 20° (15° is better; Warriss *et al.*, 1991), should be of a stair-step type (inter-cleat distance ≤150 mm) and covered by rubber to prevent pigs from slipping and producing noise (Christensen and Barton-Gade, 1996).

The weather conditions (temperature and relative humidity, RH) are also very important at this stage. Usually, to prevent mortality in truck due to hyperthermia it is recommended to load pigs early in the morning in summer (Eikelenboom, 1988). Furthermore, when the temperature is above 10 °C and the loading time is very long, pigs should be given a shower either before being loaded or on the truck (Schutte *et al.*, 1996). French studies proved that a 5 minute shower prior to departure from the farm gate reduces the mortality rate during transit by 25% (Chevillon, 1998).

2.3. Transport

Transportation is a novel situation for pigs and as such it is capable of provoking apprehension. Actually, it exposes the animals to several new potentially stressful factors, such as unfamiliar noises and smells, vibrations and sudden speed changes of the truck, variations of environmental temperature and lower individual social space.

A detailed overview on the effects of transport conditions (vehicle design, loading density, and transport time and distance) on stress response and meat quality in pigs is given in Chapter 6.

2.4. Unloading

Once the abattoir is reached, pigs should be unloaded from the truck as soon as possible (AAFC, 1993). Driessen and Geers (2001) showed a higher muscle acidification in the muscles of pigs unloaded after more than 30 min wait at high ambient temperatures (> 20 °C). However, if delay is unavoidable pigs must be provided with adequate ventilation in the truck. The waiting time to unload after arrival at the abattoir is very variable. In the abattoirs surveyed in UK, the waiting time ranged from 5 min to several hours (Jones, 1999) and in Canada some loads waited for up to 4 h before unloading (Aalhus *et al.*, 1992). On arrival, a 'booking-in' schedule, i.e. a strict coordination of truck arrivals with the predicted number of pigs in lairage, lairage capacity and speed of operation, would help to reduce waiting times. The availability of unloading quays can also affect the unloading time, especially in case of simultaneous arrivals of several trucks. The higher is the number of unloading quays, the shorter will be the waiting time on the truck. Ideally, the number of unloading quays should equal the number of rows of lairage pens.

Although unloading is considered less stressful than loading, increased carcass bruising and injuries due to rough handling are unavoidable at this stage unless appropriate equipment is provided. Handling problems can be caused by the lack of sheltered quays as if pigs are subjected to wind, rain and strong sunlight, they balk and often refuse to exit the truck (Jones, 1999). To avoid jamming and panic in the unloading group, the truck should be emptied gradually by unloading pigs by transport pen group rather than by deck (Jones, 1999). The first pigs should be given sufficient time to walk off the truck by themselves and then the rest will be driven by using a push-board in such a way the group is kept together.

As said previously about loading, the use of the hydraulic lift or containers to unload pigs increases the easiness of handling and shortens the off-load time (Brown *et al.*, 2005). However, in practice the most common unloading device is the ramp or bridge, sometimes combined to the lift. Keeping in mind that pigs have difficulties in descending a slope and are often pushed forward by rough handling (sticks, electric goads and kicks) and driver vocalisation (Faucitano, 2001), steep ramps (> 15-20°) are not recommended (Jones, 1999). Rabaste *et al.* (2007) showed an increase in the number of mounting, slipping and about turning in pigs unloaded with electrical goad compared to those handled with boards.

Handling problems due to hesitation and refusals of pigs to go forward can also be caused by poor lighting (dark area), height difference (> 15 cm step; SCAHAW, 2002) between the truck deck and the unloading ramp and inappropriate design and location of the unloading area. The unloading area should not have any corners to negotiate, pigs should walk straight into the lairage pen in their truck-group, a solid-gate should be dropped behind the group in order to encourage pigs to walk forward and thus be locked into position allowing adequate space for the size of the group (Jones, 1999).

2.5. Lairage

Beside creating a reservoir of animals aimed at maintaining the constant speed of the slaughter line, the function of lairage is to allow the animals to recover from the stress of transport and unloading. Whether pigs will actually get the opportunity in lairage to recover from transport and rest will depend mainly on whether they are mixed or not. Inadequate treatment of slaughter pigs in this stage or lack of environment control may result in additional stress leading to economic losses due to death, skin damage and poor meat quality (see review by Warriss, 2003). A high lairage mortality like the 0.57% mortality rate reported by Guàrdia *et al.* (1996) in the Spanish survey causes a significant economic loss to the abattoir. However, usually less pigs die in lairage than during transport and a pig death in lairage is generally accepted to be the consequence of the effects of transport stress. Nevertheless high-stress lairage systems can lead to high lactate and CPK levels in blood at slaughter and a more than two-fold higher incidence of PSE meat (Warriss *et al.*, 1994) (Table 2).

2.5.1. Lairage time

Warriss *et al.* (1992) and more recently Pérez *et al.* (2002) concluded on the basis of cortisol levels in post-slaughter blood samples that after two to three hours in lairage basal levels are reached again and therefore a resting period of this duration is required from the welfare point of view. The importance of the application of a proper resting period has been highlighted by Fortin (2002). This author showed that 3 h resting period always improves pork quality regardless of transport time, season or producer. However, in practice the resting times applied are very variable (from < 1 to 15 h) depending on the lairage area size, availability of pigs for slaughter, transport

Table 2. Comparison of blood profile and meat quality in pigs experiencing high stress and low stress lairage systems (Warriss et al.*, 1994).*

	Low-stress system	High-stress system	P
Lactate (mg/100ml)	6.4 ± 1.7	140 ± 2.4	***
CPK (U/l)	965 ± 81	1436 ± 2.4	*
PQM (µs)[1]	3.8 ± 0.06	4.7 ± 0.06	***

[1]PQM (Pork Quality Meter) > 4 = PSE.
*p< 0.05, ***p< 0.001.

time, handling procedures (i.e. mixing) and environmental conditions (Geverink *et al.*, 1996; Santos *et al.*, 1997; Gispert *et al.*, 2000).

Nanni Costa *et al.* (2002) reported that, of all preslaughter factors that they studied which influenced pork quality, lairage time was the most important. Slaughtering pigs immediately after arrival at the abattoir or after very short lairages (≤30 min) proved to reduce the number of bruises on the carcass in mixed pigs (Geverink *et al.*, 1996) and to decrease the incidence of PSE meat at stressful environmental conditions (≥35 °C and ≥80% RH) (Santos *et al.*, 1997). However, in normal conditions both no lairage and short lairage (15-45 min) can lead to a very high incidence of PSE meat (Eikelenboom *et al.*, 1991; Fortin, 2002; Hurd *et al.*, 2005). Park *et al.* (2003) reported a 22% decrease in the PSE pork incidence when applying overnight lairage instead of no lairage. It also appears that pigs not rested sufficiently after unloading are more difficult to handle in the stunning race and require more coercion (Warriss, 1996b). High occurrence of PSE meat can also be produced by the stressful treatment imposed on pigs being woken up and driven to the stunning point after being held in lairage overnight (Honkavaara, 1989b).

Longer lairage time proved to reduce the incidence of PSE meat but to increase the prevalence of DFD meat due to increased glycogen depletion in the muscles (Gispert *et al.*, 2000; Pérez *et al.*, 2002). Pérez *et al.* (2002) reported an increase in blood cortisol, CPK and lactate dehydrogenase (LDH) levels and a decrease in glucose concentrations in pigs kept in lairage for 9 hours. This long lairage without food intake would produce hypoglycaemia which would eventually result in pigs feeling weak, lethargic and sensitive to cold (Gregory, 1998). Furthermore, prolonged lairage (overnight to > 24 h) produces progressively more skin damages due to fighting, especially within large batches (up to 90 pigs) of unfamiliar pigs, and reduces carcass yield due to the combined effect of long fasting (Warriss, 1996a). To limit the negative effects of long lairage on carcass yield, pigs laired for longer than 12 h should be fed (Warriss, 1996b).

2.5.2. Handling in lairage

The benefit of providing pigs with a resting time between transport and slaughter can be lost if pigs are subjected to poor handling and stressful environmental conditions (climate and noise) in lairage. The attitude of the stockmen is of great importance. A recent study by Coleman *et al.* (2003) showed that the use of electric prod with the power turned off or on was associated with the attitude of abattoir personnel to have a positive or a negative interaction with pigs.

Troeger (1989) used blood sampling from the ear vein in lairage and showed that forced driving in groups led to higher adrenalin levels than careful driving. Handling problems are also caused by inappropriate corridors/races and pen design, discontinuites in the floor texture and colour, air drafts and lighting (Grandin, 1998). Pigs move more readily from a distinctly darker area into a brightly illuminated area (Van Putten and Elshof, 1978). Grandin (1983) mentioned that shadows will impede the movement of pigs, but Tanida *et al.* (1996) showed that 1-week old piglets did not respond to shadows and lines across the floor, and that it may be the fence poles themselves rather then their shadows at the floor that stop the animals.

With regard to lairage design, the flow of pigs proved to be better when: (1) the corridors are wide (4 pigs in a row wide), straight or with wide corners, well lighted and with few bends; (2) the pens are arranged in long rows and are narrow and long with entry and exit at opposite ends ('through-flow' pens); (3) the gates and pen walls are of solid construction. Solid-walled pens and fences would eliminate contact between pigs walking through the alleys and those held in pens and prevent stops due to distractions (Jones, 1999). Floor surface should not be slippery and should be of uniform colour (Grandin, 1998). As pigs do not drink during transport (except at truck stops), pigs need to be re-hydrated, especially at high temperatures. Hence, pens must be equipped with a system of drinkers with a ratio of one drinker per 20 pigs (Chevillon, 2001). A particular attention must be paid to the type of drinker to install as it must be of the same kind pigs were using at the farm. In practice, it is normally observed that when the drinker is different, pigs do not drink.

The EC Directive on the protection of animals at the time of slaughter or killing (93/119/EC) states that 'animals which might injure each other on account of their origin must be kept and lairaged apart from each other'. However, it is still common practice to mix different rearing groups of a producer during transport and lairage. Since pigs in general do not fight during transport (Lambooij, 1988), establishing a social dominance order will take place mainly during lairage (Guise and Penny, 1989; Karlsson and Lundström, 1992). To avoid mixing of pigs, smaller holding pens would need to be created in lairage, and pigs would need to be kept within their group during the driving procedure. Rabaste *et al.* (2007) observed that pigs kept in large groups (30 pigs) spent more time standing, fighting and were more involved in agonistic interactions (bites and head knocks) than pigs kept in small groups (10 pigs). The use of pens provided with mobile internal cross-gates favours helps to maintain smaller groups (10-15 pigs) without mixing favouring the resting behaviour (Barton-Gade *et al.*, 1992).

If mixing is necessary, fighting can be reduced by mixing small batches and providing sufficient space allowance (0.50-0.67 m^2/100kg or 1-2 pigs/m^2) (Warriss, 1996a,b; Chevillon, 2001). High stocking densities increase skin damage due to the impedement of an easy escape of attacked individuals (Geverink *et al.*, 1996).

Lairage temperatures and humidities of 15-18 °C and 59-65%, respectively, are considered as optimal to limit the physical stress (lactate levels in blood) and to decrease the occurrence of PSE meat (Honkavaara, 1989a). At ambient temperatures close to the upper limit of their thermoneutral zone (30 °C) and at high humidities (RH 85%), pigs have great difficulty in losing heat. As a result, they lie down quickly, maintaining relatively wide separation of individuals and increasing their respiration rate (Santos *et al.*, 1997). Extreme temperature (≥35 °C) and humidity (≥ 80%) can be prevented by controlled ventilation and air temperatures as well as showering.

The practice of spraying pigs with cold water (10-12 °C) possesses three distinct advantages. Firstly, it cools the pigs, reducing the strain of the cardiovascular system and improving meat quality (PSE). It has been evidenced that showering pigs with an average flow rate of 27 l/min/m^2 once an hour produces a drop of temperature in the loin muscle of more than 3 °C improving meat quality (Long and Tarrant, 1990). Aaslyng and Støier (2002) reported lower meat exsudation from pigs having been showered in lairage. Secondly, although it increases general activity of pigs during lairage (Knowles *et al.*, 1998), spraying pigs with cold water reduces aggressive behaviour and facilitates greater ease of handling upon entrance into the stunning chute (Weeding *et al.*, 1993). Finally, it increases the electrical stunning efficiency by lowering the skin impedance, which leads to an easy and rapid achievement of unconsciousness prior to slaughter.

At temperatures between 10 and 30 °C and RH lower than 80% showering in lairage is desirable. Below 5 °C, showering is not recommended as it causes animal shivering and may lead to darker meat (DFD) due to muscle energy depletion to maintain a constant body temperature (Knowles *et al.*, 1998). Although it is generally accepted that the shower regime should be intermittent and not longer than 30 min in order to get the greatest cooling effect and reduce activity and aggression (Weeding *et al.*, 1993; Jones, 1999), there is no agreement on the time and number of shower applications (Table 3).

The noise produced by the machinery, pressure hoses, pig and human vocalisation represents a source of stress which pigs cope with by huddling and escaping from the source of sound (Geverink *et al.*, 1998). High sound levels in lairage (> 100 dB) proved to increase the levels of lactate and CPK in blood and the proportion of PSE meat (Warriss *et al.*, 1994).

Moving pigs forward to the stunning point is a very important source of stress in slaughtering pigs, as shown by the increased concentration of cortisol, lactate and CPK in blood (Hunter *et al.*, 1994; D'Souza *et al.*, 1998), higher body temperature (Gariépy *et al.*, 1989; Schaefer *et al.*, 1989), higher skin damage (Faucitano *et al.*, 1998) and reduced meat quality (Klont and Lambooij, 1995). At this stage handling facilities are of primary importance, given the need to handle pigs faster, so as to follow the speed of the slaughter-line. The combination between higher speeds (1000 pigs/h) and poorly designed handling systems is detrimental to animal welfare as to handle pigs at this rate requires considerable coercion (goads and sticks), and to abattoir economics as just the presence of a reluctant to move pig can disrupt the even flow of the whole group (Faucitano *et al.*, 1998). The use of electrical goads must be limited at this stage as it increases mounting behaviour between pigs in the group (Figure 2) leading to higher incidence of bruised carcasses and PSE pork (Rabaste *et al.*, 2007). To limit these effects, pigs must be moved in small manageable groups (≤15 pigs) (Barton-Gade *et al.*, 1992). Støier *et al.* (2001) showed that keeping pigs in groups of 15 while moving to the stunner and allowing them to walk at their own pace without being goaded decreased drip losses in meat.

Table 3. Summary of recommendations on shower time and number of applications for pigs in lairage.

Shower time	No. of applications	Reference
30 min	1 on arrival and 1 just before moving to stunning	Warriss (1994)
10 min in winter/20 min summer	1 on arrival and 1 just before moving to stunning	Chevillon (2001)

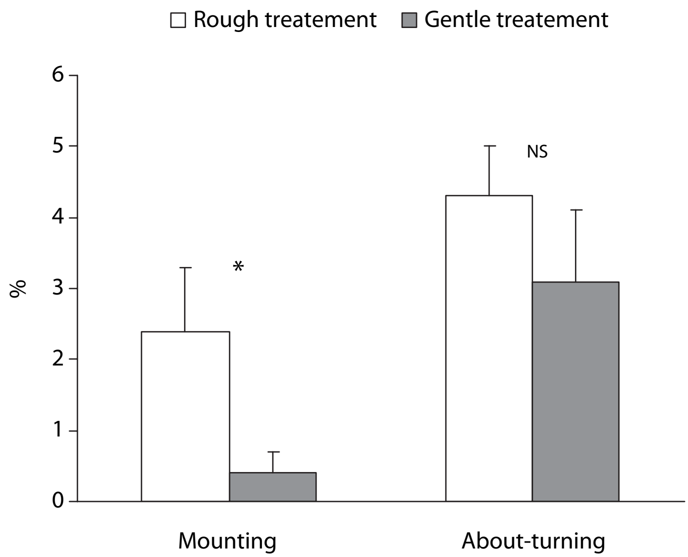

*Figure 2. Effects of handling quality on the behaviour of pigs in the stunning raceway (*p < 0.05; NS: not significant) (modified from Rabaste* et al.*, 2007).*

The arrangement of the pens and the alleys and the distance between the pen and the stunning point must be such that movement is facilitated and the flow of pigs is constant and rapid. Pigs are less stressed (lower heart rate) when the time elapsing between the exit from the lairage pen and the entrance into the stunning conveyor is less than 3 min (Chevillon, 2001). The herringbone arrangement of pens, where pens are set on an angle of about 45° to the entry and exit passages, proved to induce easy movement out of the pen (Warriss, 1994). A higher improvement in the practical handling of pigs has been achieved with the introduction of the Danish lairage design which incorporates smaller pens holding only 15 pigs and automatic push gates to move the animals. The lower stress imposed on the animals and the reduced interaction with the handlers proved to reduce the skin damage and the incidence of DFD meat and blood splashes (Barton-Gade *et al.*, 1992).

Pigs find the progressive passage from a free-moving group situation into a single line of oriented and restrained individuals very stressful, as showed by the seven- to 12-fold increase of the adrenaline levels in blood and the higher heart rate (Troeger, 1989; Griot *et al.*, 2000). At this stage it is impossible for the handler to have any other form of contact with the pig in the race, other than with the electric goad or prod of some sort. Jamming and subsequent coercion seem reduced when a group size of 10 pigs or less is maintained and the space allowance in the crowd pen prior to the enclosed race is 0.6 m^2/pig (Figure 3). In case of the stun-pen used for 'on-floor' electric stunning, the group size should be of maximum 8 pigs allowing a space of 1.2 m^2/pig (Jones, 1999). The design of the race entrance and of the enclosed race itself is also very important. The entrance to the enclosed race should be wide (39 cm for 100 kg pig), the race itself should be as short as possible with no bends, shadow-free lighting, moderate uphill slope (6°), 35-40 cm wide and at least 120 cm high (Jones and Guise, 1996). A too long (> 3 m) and wide race (2 pigs wide) and the absence of hold-down bars showed to increase heart rate and blood cortisol level and to promote riding/mounting activity in the chute increasing the skin damage score on the carcass (Hartung *et al.*, 1997; Faucitano *et al.*, 1998).

Neither single nor double races work well when leading up to the stunning point, especially in case of the gas stunning system. Once in the race, forward motion towards the stunning cradle is interrupted to enable the first pigs in the queue to enter the cradle. Hence, the following pigs have to wait in line for 10 sec before walking forward

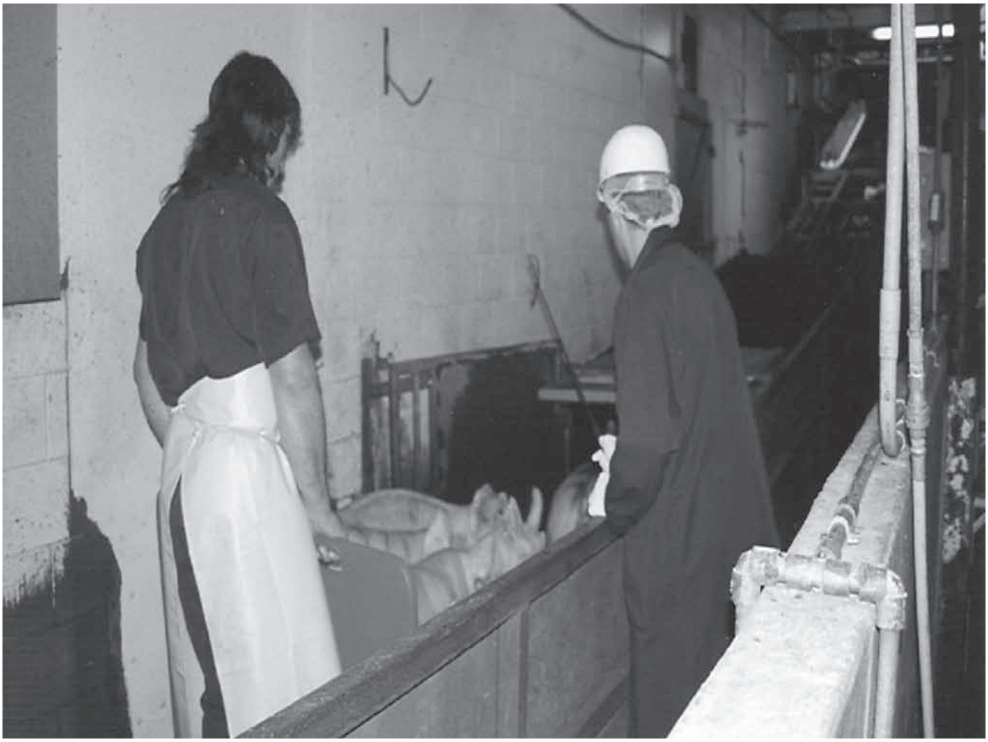

Figure 3. Handling small groups and the use of boards favour the entrance into the stunning race (L. Faucitano, AAFC).

again. This 'stop-start' action increases coercion (70-100% goading) to encourage the pig movement (Jones, 1999). Easiness of handling pigs on the entry into the CO_2 system can be improved by using a semi-circular pen, either in combination with a twin race or with direct entry into the stunner (Anil *et al.*, 1998). To avoid the need to reduce the flow of pigs to a single or double file a new system, operating at a speed of 800 pigs/h, has been developed in Denmark (Christensen and Barton-Gade, 1997). According to this system, pigs are driven in groups of 15 pigs from the pen to the stunning area by the means of pushing gates. The easiness of handling is increased as the group size is automatically and progressively reduced into groups of 5 pigs which are then loaded as a group into the stunning cradle (group-wise stunning system). Compared to a double race system, the group-wise handling system resulted in lower PSE (3.8 vs. 6.2%) and a lower incidence of unacceptable blood splashing (3.2 vs. 8.8%) and bruises (1.9 vs. 6.2%) due to reduced prodding and muscle exercise (Christensen and Barton-Gade, 1997). Franck *et al.* (2003) proved the efficiency of the automated driving of groups of pigs to the CO_2 stunning cradle in the reduction of PSE-zones in the ham compared to a traditional system driving pigs in a single file using electrical goads.

3. Conclusions

The increased consumers' concern about production methods and the losses due to *ante mortem* poor handling urge for adequate response strategies by agribusiness and food companies. Indeed, the poor environmental conditions experienced by pigs particularly in some stages prior to slaughter can lead to reduced welfare and mortality losses and can irreversibly affect the carcass (bruises) and meat quality (PSE, DFD and blood-splashed meat). The image of pork production and the economy of the meat industry can be improved only through adequate control at the various pig production line stages, and particularly at slaughter.

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Chapter 8. Welfare of pigs during stunning and slaughter

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Abstract

Humane slaughter, method of inducing death in animals without causing avoidable anxiety, fear, pain, suffering or distress, regulations require that stunning methods should induce immediate loss of consciousness. If the stun is not immediate, the induction of unconsciousness should occur without causing the animal avoidable fear, pain, anxiety, suffering or distress. The duration of unconsciousness must be longer than the sum of time that it takes to perform shackling and bleeding and the time to onset of death through blood lose at slaughter. Head-only electrical stunning is universally practised to stun pigs under commercial conditions, where high throughput rates are required. Electrical stun/kill is also performed by either passing an electric current from head-to-body using a single current cycle or by applying a current across the chest of head-only electrically stunned pigs (within 15s from the end of stun) to induce cardiac ventricular fibrillation using two separate current cycles. A minimum current of 1.3A delivered using 50 to 1500 Hz current will be necessary to induce satisfactory stunning and the same current level could also be applied using a 50 Hz AC to achieve stun/kill in single and two current cycle methods. Carbon dioxide stunning of pigs is becoming common however this method remains to be controversial on animal welfare grounds. This is because inhalation of high concentrations of carbon dioxide (40% or more in air) is extremely aversive to pigs and induces severe respiratory distress prior to the onset of unconsciousness. It has been recommended in the UK that carbon dioxide stunning of pigs must be phased out over the next five years. Alternatively, argon or nitrogen-induced anoxia (< 2% residual oxygen) is reported to be the pleasant way of loosing consciousness in humans and, certainly, pigs do not seem to find it aversive and they show no signs of distress during the induction of unconsciousness. Captive bolt stunning is the only stunning method available in some developing countries and is also used as a back-up method to stun pigs showing signs of return of consciousness in high throughput abattoirs.

Keywords: animal welfare, pigs, stunning, electrical, carbon dioxide, anoxia, captive bolt, slaughter

1. Introduction

'Animal Welfare is not a term that arose in science to express a scientific concept. Rather it arose in society to express ethical concerns regarding the treatment of animals' (Duncan and Fraser, 1997). This statement is vindicated by the success of RSPCA (Royal Society for the Prevention of Cruelty to Animals) sponsored Freedom Food scheme in the United Kingdom (www.rspca.org.uk) and the number of animal welfare-based quality assurance schemes operating around the world (for example, www.freefarmed.org in the USA). The European Union Treaty of Amsterdam, which came into force on 1st May 1999, explicitly acknowledges that animals are sentient beings, rather than agricultural products or commodities, is an example of response to the society's concern for animal welfare (www.eurogroupanimalwelfare.org; http://ec.europa.eu/index_en.htm). Similarly, the World Organisation for Animal Health, (www.oie.int/eng/en_index.htm) has established a Working Group on Animal Welfare through the Resolution No. XIV bringing in experts from five continents and the Food and Agriculture Organisation (www.fao.org) and World Trade Organisation (www.wto.org) are also discussing animal welfare to reach global standards.

Education played a very important role in this chain of events. For example, Harrison (1964) revealed to the public during 1960s that farm animal welfare could not be ensured by having prevention of cruelty laws and since then, in response to society's concern, welfare regulations were introduced in the UK and Europe. Although the existence of prevention of animal cruelty laws in some countries shows that animal welfare is not necessarily a concern of the affluent western society, it is rather a universal realisation, proactive measures are still needed in many other countries. In this regard, Webster (1994) concludes his book 'Mankind has capacity for compassion (to animals), and once we have met our immediate needs, we can afford to be compassionate. When we can afford the cost of altruism we can enjoy the benefits. Until he extends the circle of his compassion to all living things, man will not himself find peace'.

One of the synonyms of the term 'sentient' is 'conscious'. It is therefore mandatory in many countries that all animals intended for human consumption must be rendered unconscious prior to slaughter and they should remain so until death supervenes through blood loss (exsanguination).

Animal welfare in the context of stunning and slaughter or killing can be defined as 'inducing death in animals without causing avoidable anxiety, fear, pain, suffering or distress', which is normally referred to as humane slaughter. In general, stunning methods should induce immediate loss of consciousness. If the onset of unconsciousness is not immediate, the induction of unconsciousness with a stunning method should not cause avoidable anxiety, fear, pain, suffering or distress. The duration of unconsciousness induced by a stunning method should be longer than the sum of time interval between the end of stun and sticking (severing blood vessels) and the time it takes for bleeding to cause death. Therefore, in order to prevent the return of consciousness, effectively stunned animals should be bled out swiftly and all the major blood vessels supplying oxygenated blood to the brain must be severed. Animals showing any signs of recovery of consciousness following stunning must be immediately re-stunned using appropriate back-up stunning device. A number of stunning methods have been modified to induce stun/kill (death), rather than mere loss of consciousness. Understandably, stun/kill methods do not rely on bleeding to cause death and therefore eliminate the chances of recovery of consciousness.

2. Handling during stunning

Among the farm animals slaughtered for human consumption, pigs are arguably the most susceptible species to suffer stress during transport, lairage, stunning and slaughter. Movement of pigs from lairage or resting pens to the point of stunning is probably the most critical process which can compromise animal welfare very seriously at slaughter, with significant economic consequence occurring as a result of poor meat quality. Animals that are subjected to distress during this period are also very likely to be difficult to restrain during stunning. Therefore, animal pre-slaughter handling facilities should be carefully designed, constructed and the environment controlled to keep the level of distress to the minimum. Understanding the behaviour of animals and principles of handling will certainly help to achieve this (Grandin, 1991, 1996; also visit www.grandin.com/index.html). Faster throughput rates require well-designed and constructed handling and restraining facilities to achieve good welfare standards. Personnel involved in handling, stunning and slaughter of animals should also be properly trained and certified to ensure and maintain these standards.

3. Stunning methods

Electrical stunning is universally used to render pigs unconscious and insensible prior to slaughter. Carbon dioxide stunning is most commonly used in the Scandinavian countries. The use of argon or nitrogen-induced anoxia has been evaluated in the UK but, owing to the lack of appropriate stunning equipment, it is yet to be implemented commercially. The use of captive bolt for stunning pigs under high throughput commercial conditions is not common in Europe. However, it remains to be the only method available for stunning food animals in the developing countries.

A good understanding of the scientific basis of stunning procedures is vital to the successful implementation of animal welfare standards during stunning and slaughter. It is generally assumed that the ‘near-threshold’ depolarised state of neurones in the brain is necessary for perceptual process to occur and consciousness to exist. In this regard, electroencephalogram (EEG) or electrocorticogram (ECoG, referred to as EEG from now on) is widely used to record the brain electrical activity to determine the depth of unconsciousness during anaesthesia or brain disorders in conscious humans. Research on the origin of rhythmic brain electrical activity in various frequency (Hz) bands indicates that complex homeostatic systems involving large neuronal populations regulate the EEG.

The electrical activity recorded in the EEG can be classified into *delta* (< 4 Hz), *theta* (4 to 7 Hz), *alpha* (8 to 13 Hz) and *beta* (> 13 Hz) frequency bands. The amplitude and frequency of activity seen in the EEG is related to the degree of synchronisation of activity of neurones. For example, low-amplitude and high frequency (*beta*) waves occurring in the EEG during conscious state is generated by a large number of non-synchronised, independently firing neurones. With an increasing dose of most anaesthetic agents the spontaneous EEG changes progressively to high amplitude, lower frequency (*delta*) pattern. The increase in amplitude results from an increase in the degree of synchronisation in the electrical activity of neurones and the decrease in frequency of activity seems to correlate with a reduction in cortical metabolism.

Under the conditions of normal neuronal function, the excitatory amino acid (EAA) neurotransmitters facilitate the excitatory bursts while inhibitory amino acid (IAA) neurotransmitters inhibit such actions. As the two neurotransmitter systems are found together, it is believed that they jointly provide a controlled balance of neuronal activity. It has been known that low levels of deviations from the normal contents of EAA and IAA neurotransmitters can lead to an altered state of mind in humans (e.g. arousal, anxiety and depression).

Stunning methods should effectively disrupt the normal state of neurones or neurotransmitter regulatory mechanisms in the brain to render animals, including birds, unconscious and insensible. In other words, stunning methods induce pathological brain states that are incompatible with the persistence of consciousness and sensibility. The pathological brain states could be determined, unlike the state of consciousness, using scientific tools such as EEGs. A scientific report published in 2004 by the European Food Safety Authority (EFSA) provides details of various stunning or killing methods (can be accessed at www.efsa.europa.eu/EFSA/Scientific_Opinion/opinion_ahaw_02_ej45_stunning_en1.pdf).

3.1. Electrical stunning

Electrical stunning of food animals was introduced on the basis that when a current of sufficient magnitude is passed across the brain it induces hyper-synchronisation of the activity of neurones. Hyper-synchronisation of activity of large groups of neurones in the brain, involving both the cerebral hemispheres, is referred to as grand mal or generalised epilepsy and is a pathological extreme of neuronal synchrony. Experimental models of both focal and primary generalised epilepsies have revealed the importance of the intrinsic (membrane current) properties of neurones and the synaptic networks that connect them. Focal epilepsies involve small groups of neurones and depend on excitatory networks within individual cortical structures, where as, generalised epilepsies involve large groups of neurones and require widely dispersed neuronal networks. Understandably, the associated levels of consciousness and sensibility also vary under these circumstances.

In humans, the occurrence of *grand mal* epilepsy, characterised by the high amplitude (> 100 microvolts), low frequency (8 to 13 Hz) activity in the electroencephalogram (EEG), is always associated with unconsciousness. During grand mal epilepsy, the classic tonic and clonic seizures occur. Electrical stunning, i.e. the passage of sufficient electrical current across the brain, of an animal induces such an epileptic activity in the brain and, as a consequence, render the animals unconscious and insensible (Hoenderken, 1978; Lambooy, 1981; Gregory, 1986). Grand mal epilepsy is always followed by a period of quiescent EEG and it is assumed that the animals are unconscious until the quiescent phase lasts in the EEG, which is known as spreading depression. A typical example of the changes occurring in the total power content (V^2) in the EEG of an electrically stunned animal is presented in Figure 1.

It is worth noting that seizure is only a symptom and the site of origin of seizure in the central nervous system determines the associated state of consciousness and

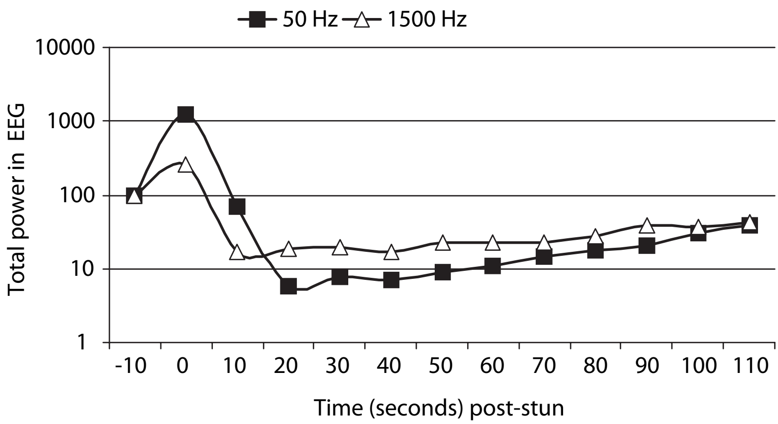

Figure 1. Electrical stunning induced changes in the EEG total power content (V2) in log units.

sensibility. Therefore, to avoid confusion, epilepsy and seizure are used in this article to refer to hyper-synchronisation of neuronal activity in the brain and physical convulsions, respectively. Electrical stunning of animals with a current lower than the threshold necessary to induce grand mal or generalised epilepsy will induce a potentially painful arousal or seizure rather than unconscious state.

The neurochemical basis of the occurrence of epilepsy in humans is also well established. When two fast acting EAAs, namely glutamate and aspartate, are released excessively into the extra cellular space they play important roles in the initiation, spread and maintenance of epileptic activity in the brain (Meldrum, 1994). Gamma amino butyric acid (GABA) is the principal inhibitory amino acid (IAA) neurotransmitter and, when released into the extra cellular space, it inhibits neuronal activity and hence epilepsy (Meldrum, 1984).

Based on the understanding of epilepsy in humans and experimental animal models, Cook *et al.* (1992) have investigated head-only electrical stunning of sheep. A summary of their results is presented in Table 1.

Based on these, it was concluded that the development of epilepsy following head-only electrical stunning of sheep is dependent on EAAs and the suppression of reflexes (such as, response to rubbing of a paint brush over eye lash, brush of the corneal surface, light beamed into pupil, ear pinching and pedal web pinching) is attributed

Table 1. Neurochemical evaluation of electrical stunning in sheep (from Cook et al.*, 1992).*

- Head-only electrical stunning induced epilepsy is dependent on the extra cellular release of glutamate and aspartate
- GABA is also released into the extra cellular space following stunning, albeit on a slightly slower time profile than glutamate and aspartate; this effect can occur independently of EAAs release
- Administration of a mixture of EAA (N-Methyl D-Aspartic acid) receptor antagonists (2-amino-5-phosphonovaleric acid, APV and 2-amino-7-phosphonoheptanoic acid, APH) reduced the duration of epileptic activity following electrical stunning
- Administration of a GABAa receptor antagonist (bicuculline; Serva Ltd) increased seizure duration and reduced the time to return of physical reflexes
- Administration of a GABAb receptor agonist (baclofen; Sigma Ltd) increased the time to return of physical reflexes
- Administration of a mixture of GABA transmission facilitator (Zolazepam; Virbac Ltd) and EAA receptor antagonist (Tiletamine; Virbac Ltd) resulted in a dose dependent reduction in the duration of electrical stunning induced epileptic activity

to GABA release. Both the neurotransmitter systems, synergistically, produce unconsciousness and analgesia required to ensure animal welfare following electrical stunning. Although, GABA release can occur, as a neuronal reflex mechanism in response to the release of EAA (to prevent neuronal exhaustion and loss), GABA release can occur independently of the EAAs.

Cook *et al.* (1995) further elucidated, using a combination of microdialysis and electrophysiological techniques, the effect of head-only electrical stunning duration (0.1, 0.2, 0.5, 1, 2, 4, 8, 12 and 20s) in sheep. In this experiment, stunning of sheep with 1.0A current (50 Hz, 500V) for less than 0.2s failed to induce epilepsy in the EEG and resulted in the release of glutamate and aspartate in the brain to the levels associated with arousal, rather than that is necessary to induce epilepsy. At duration of 0.2s, the stunning parameters induced epilepsy and excessive release of EAAs in the brain. The duration of epilepsy and the levels of EAAs and GABA increased with the stun duration of up to 4.0s. The brain extra cellular glutamate (from 100 to 180 micromoles per liter) and GABA (from 10 to 45 micromoles per liter) concentrations increased with the seizure duration (18 to 32s). The release of EAAs peaked within 2 to 4 min of the stun and then fell, where as, GABA concentrations peaked between 4 and 8 min and stayed at that level until 10 to 14min post-stun. Based on these results, it was concluded that electrical stunning of sheep with 1.0Amp for longer than 1s would provide 25s of unconsciousness and insensibility.

There is some evidence to suggest that, at a given current level, the depth and duration of unconsciousness induced by electrical stunning is determined by the duration for which the current stays at the maximum level within each cycle, otherwise known as the period (period = 1000/frequency). In this regard, electric currents of 50, 400 and 1500 Hz sine wave AC have periods of 20, 2.5 and 0.67 milliseconds (ms), respectively. It is therefore possible to suggest that the impact of a stunning current depends upon the period of current used and it decreases markedly when the period is below the threshold limit necessary to induce depolarisation of neurones (at least in poultry see Raj, 2006 for details). This implies that the depth and duration of unconsciousness decrease as the frequency of the stunning current is increased. For example, as shown in Figure 1, the magnitude of changes in the EEG total power (V^2) content due to epilepsy and spreading depression that ensues after the termination of epilepsy are greater following stunning with a 50 Hz sine wave AC than 1500 Hz AC. The effectiveness of head-only electrical stunning also depends upon at least two other factors. Firstly, the stunning electrodes (tongs) should be placed on either side of the head, between the eyes and base of the ears, such that they span the brain. Secondly, the amount of current applied to the brain must be sufficient to induce immediate onset of epilepsy. For example, under the ideal tong position, a current of less than 0.5A delivered using a 50 Hz sine wave alternating current (AC) would be sufficient, whereas, when the tongs are placed behind the ears a current of 1.3A would be necessary to stun pigs (Hoenderken, 1978; Anil, 1991). Under commercial conditions, it is not always easy to place the electrodes in the ideal position and therefore a minimum of 1.3A is recommended.

The amount of current flowing through the brain is determined by the amount of voltage applied during the stun (Ohm's Law). At a constant voltage, the amount of current flowing through the brain is inversely proportional to the total electrical resistance in the pathway between the two electrodes or tongs. In other words, the maximum voltage available to the stunner will determine how soon the recommended current level is reached during the application of the stun. Low voltages (e.g. < 150V) may take longer time to breakdown the electrical resistance in the pathway and hence may not induce an immediate stun. If the stun is not immediate (e.g. less than a second), animals will experience a painful electric shock before unconsciousness is induced. Research has shown that a minimum of 240V will be necessary to deliver this amount of current to pigs (Berghaus and Troeger, 1998). However, higher voltages (> 400V) are commonly used in automated stunning systems to improve efficiency.

It is also known that the cleanliness and condition of stunning electrodes, effective surface area of electrode that is in contact with the animal's head, electrical properties of the electrode material (e.g. resistance) and the pressure applied to the head during the stun play important roles in determining the efficiency of the current flow and hence the stun. Constant voltage stunners do not always ensure a predetermined current is immediately delivered to the animal, especially when the electrical resistance in the pathway is too high. Therefore, implementation of a constant current stunner, which continuously measures the electrical impedance in the pathway and modulates the voltage required to deliver a pre-determined current, will induce immediate stun and improve pig welfare. It has been reported that when head-only electrical stunning is applied with 1.3A using a constant current stunner, a minimum current flow time of 0.3s is necessary to induce epilepsy in the brain (Berghaus and Troeger, 1998). Similarly, research into head-only electrical stunning of sheep has shown that the recommended current of 1.0A (500V) must be applied for longer than 0.2s to induce a satisfactory stun (Cook *et al.,* 1995). These results imply that it takes 0.2 to 0.3s for the stunning voltage to breakdown electrical resistance in the pathway before it delivers sufficient current to the brain.

Automatic high voltage electrical stunning systems are commercially available for high throughput abattoirs. These systems, incorporated with different forms of restraint, are designed for 80 to 120 kg slaughter weight pigs and will require adjustments if used for pigs outside this weight range. Among the restraining methods, monorail conveyor belt seems to be better than other types on animal welfare grounds.

Under commercial conditions, the effectiveness of electrical stunning can be assessed from the tonic-clonic seizures and behaviour of pigs. During and immediately following the application of head-only stunning, the hind legs will be flexed under the body leading to collapse of the animal (if it is not prevented by the restraining method), the forelegs may initially be flexed but soon extends rigidly, breathing will stop and eye balls remain fixed. All these signs last for the duration of tonic seizure following effective electrical stunning, usually 10 to 20s from the start of the stun. The clonic seizure, which follows tonic seizure, can be recognised from the occurrence of kicking or paddling movement of the legs. It is worth noting that two clonic phases occur in electrically stunned pigs and animals resume breathing rhythmically at the end of first clonic phase, which is the earliest sign of return of consciousness in pigs and sheep (Simmons, 1995; Velarde *et al.*, 2002). It is worth noting that the amount of electric current necessary to induce seizures is less than that required to inducing epileptiform electrical activity in the brain. Induction of seizures (i.e. convulsions) without the occurrence of epileptiform activity in the brain (i.e. unconsciousness) would be extremely painful. The return of corneal reflex is not a reliable indicator of the return of consciousness in electrically stunned animals (Gregory, 1998).

The minimum time to return of rhythmic breathing following effective head-only electrical stunning of pigs is reported to be 37s (Anil, 1991). Research has also shown that, when a thoracic or chest stick (severing aorta or brachiocepohalic trunk) is performed in pigs, the time to onset of profound brain failure is 22s (Wotton and Gregory, 1986). By subtracting the time to onset of profound brain failure following an accurate thoracic stick from the minimum duration of apparent unconsciousness produced by an accurate stun, the maximum acceptable stun-to-stick interval can be calculated as 15s. It is worth noting that the size of the sticking wound should also be large (> 10 cm) enough to facilitate rapid bleed-out and hence on set of death before scalding. Pigs showing signs of recovery of consciousness following stunning must be re-stunned using a captive bolt.

3.2. Electrical stun/kill

Electrical stun/kill method is carried out by applying an electric current from head-to-body (one current cycle) or head-only electrical stunning immediately followed by a second current cycle applied across the chest to induce cardiac ventricular fibrillation (two current cycles). In one current cycle method, the front electrode (head electrode) must be placed in front of the brain and the rear electrode (body electrode) must be placed on the body, behind the position of heart, such that the two electrodes span the brain and the heart. The electric current employed in this method must always be 50 to 60 Hz sine wave alternating current to achieve humane stunning/killing because high frequencies do not induce cardiac ventricular fibrillation. Effective stunning/

killing can be achieved under this method by using a minimum current of 1.3A. In two current cycles method, head-only electrical stunning is performed using 1.3A of 50 to 1500 Hz current just prior to applying a 50 Hz sine wave AC current across the chest. The voltage necessary to induce cardiac ventricular fibrillation depends upon, at least, the orientation and proximity of the electrodes to the heart and total electrical resistance in the pathway. Scientific literature concerning termination of ventricular fibrillation (VF), in pig models, by electrical counter-shocks reveals that transthoracic electrical resistance is affected by size of the electrodes, applied pressure, the phase of respiration during which the shock is applied, use of coupling gel and its salt content and the distance between the electrodes, which is dependent upon the circumference of chest during transthoracic current application. It is worth noting that published scientific information regarding the effects of these variables during the induction of cardiac ventricular fibrillation in food animals is lacking. However, some people would argue that this method may be misused to mask the signs of recovery of consciousness in inadequately (head-only) stunned animals, and therefore, discouraged.

Properly applied electrical stun/kill method should result in death in all the pigs. However, these animals will show tonic convulsions leading to relaxation and some may show gagging or gasping for a short period of time.

3.3. Carbon dioxide stunning

Inhalation of carbon dioxide induces respiratory and metabolic acidosis, which reduces the pH of blood and, hence, the cerebrospinal fluid (CSF) thereby leading to its anaesthetic effect. Research has shown that the rate of induction of unconsciousness with carbon dioxide depends upon the concentration of this gas in the stunning unit, which is normally a concrete well (Troeger and Wolterdorf, 1991; Raj and Gregory, 1996). Carbon dioxide stunning of pigs remains controversial in Europe for at least three important animal welfare reasons.

Carbon dioxide, being an acidic gas, is pungent to inhale in high concentrations (40% by volume or more in air). Therefore, it is hardly surprising to note that the majority of pigs (88%) avoid an atmosphere containing high (> 80% by volume) concentrations of carbon dioxide (Cantieni, 1976; Raj and Gregory, 1995). This aversion was found to be greater than the motivation to obtain a reward (apples) in the carbon dioxide atmosphere, even after 24h fasting (Raj and Gregory, 1995). This aversion to carbon dioxide is not only evident but also creates problem with the loading of pigs into carbon dioxide stunning systems fitted with solid swing doors at the entrance. Under this situation, when the door opens outward, carbon dioxide is fanned out of the unit into the face of pigs awaiting loading. The concentration of carbon dioxide blown this way can be high enough to cause aversion, and hence, pigs resist moving into the stunning unit.

Carbon dioxide is also being a potent respiratory stimulant, causes severe hyperventilation prior to loss of consciousness. Hyperventilation occurs during exercise as well as inhalation of carbon dioxide. Carbon dioxide-induced hyperventilation differs, however, in that carbon dioxide is more potent than exercise in inducing dyspnoea (breathlessness), and with carbon dioxide inhalation there is a greater feeling of being unable to breathe deeply enough (Gregory *et al.*, 1990). Exercise induces dyspnoea at a given concentration of carbon dioxide and it also results in gradual increases in the blood carbon dioxide concentration. On the other hand, inhalation of high concentrations of carbon dioxide results in rapid increases in carbon dioxide concentration, and this is more effective in producing dyspnoea (Stark *et al.*, 1981). In humans, such a rapid increase in blood carbon dioxide (e.g. during acute asthma) has been known to trigger panic attacks. Owing to the respiratory distress, some pigs exposed to less than 70% carbon dioxide in air were found to show escape attempts (Raj and Gregory, 1996). Dodman (1977) observed that, when pigs are presented with an unpleasant situation, the first reaction is to back away and this behaviour was evident in 60% of the pigs that were exposed to a high concentration of carbon dioxide. Dodman (1977) also reported that 60% of pigs showed some degree of 'excitement' prior to loss of posture and, this behaviour was found to be severe in 20% of the total number of pigs used in his study. It is very likely that the 'excitement' reported by Dodman is similar to the vigorous shaking of head observed in pigs during the induction of unconsciousness with a high concentration of carbon dioxide in air (Raj and Gregory, 1996).

Although the time to onset of breathlessness depends upon the concentration of carbon dioxide, the cumulative respiratory distress occurring in conscious state would appear to be very similar between 40 to 90% carbon dioxide in air (Raj and Gregory, 1996). Grandin (1988) reported that genetically stress susceptible (e.g. Halothane positive and Napole genes) breeds of pigs show vigorous reaction to carbon dioxide gas. In this regard, Hampshire-type pigs seem to show more severe reaction to carbon dioxide than Yorkshire- or Landrace-type of pigs. However, from animal welfare point of view, carbon dioxide stunning is considered to be better than a badly performed electrical stunning (Dodman, 1977). Webster (1994) on the other hand argues that 'the best of the existing stunning systems based on carbon dioxide undoubtedly cause more distress at the point of stunning than the best of the high voltage electrical stunning systems. However, the aim is to minimise all the stresses likely to be expected by pigs in the abattoir and the best of the carbon dioxide systems (group stunning) do permit free, minimally-stressed movement of pigs right up to the point that they enter the gas chamber'.

The time to loss of consciousness during exposure of pigs to 80 to 90% carbon dioxide is highly variable and it could be as long as 38s (Hoenderken *et al.*, 1979; Raj *et al.*, 1997). Therefore, it is clear that the pigs will have to suffer severe respiratory discomfort, albeit for a short time. In contrast with these findings, Forslid (1987) reported that pigs become unconscious before they show motor reactions and found no evidence to suggest that pigs are subjected to emotional stress during carbon dioxide stunning. The results of a more recent study, in which evoked potentials (somatosensory evoked potentials) in the brain was used to determine the unequivocal loss of consciousness, indicated that some pigs could remain conscious for up to 36s during exposure to more than 80% carbon dioxide in air (Raj *et al.*, 1997).

Considering the animal welfare concerns, the Farm Animal Welfare Council in the UK (www.fawc.org.uk) has recently recommended to the government that the use of carbon dioxide for stunning pigs must be phased out over the next five years (FAWC, 2003).

Nevertheless, two main types of carbon dioxide stunning systems, dip-lift and paternoster, are used at present to stun pigs under commercial conditions. Exposure of pigs, within 15s from leaving the atmospheric air, to a minimum of 70% of carbon dioxide by volume in air at the top and a minimum of 90% at the bottom of the unit is recommended. Under these conditions, a minimum exposure time of 90s is recommended. Understandably, the proportion of pigs killed with the gas will increase as the exposure time is increased. In some countries, for example UK, it is a legal requirement that pigs must be held in carbon dioxide atmosphere until they are dead (stun/kill method). Under the dip-lift system, pigs are loaded on to a lift, lowered into the gas for a predetermined time. Modern dip-lift systems are capable of accommodating small groups of pigs and thus suitable for large throughput abattoirs. In particular, the group handling and loading systems are beneficial to animal welfare under the modern systems (Christensen and Barton-Gade, 1997). Paternoster systems on the other hand are continuous ones and, the number of cradles, number of pigs loaded into each cradle and exposure time varies according to the model (e.g. Compact, Combi) and throughput rate.

Effective carbon dioxide stunning can be recognised from the absence of corneal reflex at the exit from the gas. The acceptable maximum stun-to-stick interval varies with the exposure time. However, under group stunning situations, the stun-to-stick interval will be rather prolonged for the last pig to be shackled and stuck. Since the maximum time to onset of a profound brain failure is 22s following a chest stick, the exposure time should induce a period of unconsciousness that is longer than the time it takes to shackle and stick the last pig plus the time to onset of brain failure in this pig. Gagging or gasping may be seen in some pigs during bleeding and it is suggestive of dying brain rather than indicative of consciousness.

A major animal welfare problem associated with the Paternoster systems is that they have a single or double race leading to the stunning unit. The race is usually very long and pigs require a considerable coercion or force to move forward. The problem is further confounded by the fact that pigs can only be loaded when there is an empty cradle available, and therefore, the process becomes stop-start. This interruption in the movement of pigs is not conducive for handling pigs without compromising their welfare (visit www.grandin.com).

3.4. Stunning with anoxia

Xenon, krypton and argon are chemically inert under most circumstances, yet all have anaesthetic properties. Xenon is an anaesthetic gas under normal atmospheric pressure; where as, argon and krypton have anaesthetic properties under hyperbaric conditions only. However, argon- or nitrogen-induced anoxia at normobaric conditions can render animals and birds unconscious and insensible very rapidly by depriving the brain of oxygen. Anoxia induced by the inhalation of argon or nitrogen differs from asphyxia, in the sense, by physiological definition, asphyxia means physical separation of upper respiratory tract and the atmospheric air (e.g. drowning, choking and strangulation) and it inevitably induces pain and distress. By contrast, anoxia induced by the inhalation of nitrogen is reported to be a pleasant or euphoric way of losing consciousness in humans (Ernsting, 1965) and recommended for euthanasia of terrestrial animals (Gregory, 1993). Inert gas (including argon and nitrogen)/oxygen mixtures are used for maintaining anaesthesia during laser surgery in the airway of horses (Driessen *et al.*, 2003).

Therefore, use of 90% argon in air has been evaluated in the UK as a potential alternative to carbon dioxide for stunning pigs. Firstly, aversion to the initial inhalation of argon was determined using passive avoidance tests, in the presence of a reward, and the results clearly indicated that pigs did not show any aversion to 90% argon in air (2% residual oxygen by volume) (Raj and Gregory, 1995). Secondly, exposure to 90% argon induced minimal respiratory distress prior to loss of consciousness (Raj and Gregory, 1996). It was also found that, during exposure to argon, pigs lost posture without any evidence of behavioural arousal. Similar observation, collapse and convulsions, have been recorded in humans within 17 to 20s of breathing pure nitrogen (Ernsting, 1963). Thirdly, the time to loss of somatosensory evoked potentials (SEPs), and thus unequivocal loss of consciousness, was determined (Raj *et al.*, 1997). In that study, the times to loss of SEPs was found to be 9-21s and the maximum time to onset of an isoelectric EEG was 86s after exposure to 90% argon in air.

More recently, further investigations were carried out under commercial conditions to determine the feasibility of using anoxia to stun/kill pigs in a paternoster carbon dioxide system (Raj, 1999). In this study, two or three pigs were loaded per cradle and immersed into 90% argon in air. The results indicated that, pigs should be ideally exposed to anoxia for 3min and stuck within 15s or exposed for 5min and stuck within 45s of exiting the gas to prevent resumption of consciousness. The results also indicated that some pigs require a minimum of 7min to die during exposure to 90% argon in air.

Owing to the prolonged exposure time required to kill pigs with anoxia, a commercially viable anoxia stunning/killing system is yet to be developed. However, since the induction of unconsciousness with anoxia is almost stress free and that small group of pigs can be stunned without isolation and restraint, some people may wish to consider the development of an anoxic stun/kill system. Although research into anoxia stunning of pigs involved argon as an anoxic agent, nitrogen can also be used either alone or in combination with a low concentration of argon. A mixture of 20 to 25% argon in nitrogen is already being used to stun/kill broiler chickens, whilst they are in transport containers, as they arrive at the processing plant in the UK.

It was also proposed recently by FAWC (2003) that pigs could be rendered unconscious first by exposing them to anoxia and subsequently killed by inducing cardiac ventricular fibrillation. Inducing cardiac ventricular fibrillation in electrically stunned pigs is an approved procedure under the existing animal welfare regulation in Europe. Warriss and Wotton (1981) successfully induced cardiac ventricular fibrillation in pigs with a transthoracic application of 90V 50Hz sine wave AC for 5 seconds.

There are a number of options available for commercial development:
1. exposure for 90 seconds to anoxia followed by induction of cardiac ventricular fibrillation, either whilst the pigs are within the gas mixture or at the exit, using an electric current;
2. exposure for 3 minutes to anoxia followed by induction of cardiac ventricular fibrillation or bleeding within 25 seconds of exiting the gas mixture;
3. exposure for 5 minutes to anoxia followed by bleeding within 45 seconds; and
4. exposure for 7 minutes followed by bleeding within 60 seconds.

Ideally, such a system should incorporate some general animal welfare principles proposed by the FAWC (2003):
- Pigs should be maintained in a stable social group with the minimum of restraint.
- Pre-slaughter handling facilities should be designed to minimise stress.
- The gas used to induce unconsciousness should be non-aversive.

- All pigs should be rendered rapidly unconscious in the gas.
- An irreversible state of unconsciousness must be reached in all pigs prior to sticking.
- There should be adequate monitoring of the system and efficient evacuation in the event of any system failure.

3.5. Captive bolt stunning

Daly and Whittington (1989) clearly demonstrated that the rapid acceleration of head due to the impact of a captive bolt with the cranium (without penetration of the cranium) to be the principle determinant of effective captive bolt stunning and firing the bolt through a trephined skull failed to induce satisfactory stunning in sheep. The main factor determining the effectiveness of captive bolt stunning is the kinetic energy delivered to the skull on impact, which in turn, depends upon the bolt velocity and mass. Another critical factor is the shooting position on the head. Cartridges or compressed air can be used to fire captive bolts under commercial conditions. The strength of cartridge or the airline pressure should be appropriate to stun pigs, chosen according to the manufacturers guidelines.

There are two categories of captive bolts: non-penetrative and penetrative. A penetrating captive bolt also induces structural damage to the brain. The duration of unconsciousness induced by a captive bolt depends on the severity of damage to the nervous tissue. For the non-penetrating captive bolt to be effective the skull of animals must be fully ossified and stunning should be accomplished without inducing fracture of skull. This is based on the fact that the energy will be dissipated or absorbed locally by the fractured skull rather than transmitting to the brain beneath. However, owing to the low margin for error, non-penetrating captive bolts are not suited for pigs.

Owing to the temperament of pigs and response to approach by human, they are arguably the most difficult animals to stun with captive bolt. In addition, the target area is small and the brain lies deep in the head with a mass of sinuses lying between the frontal bone and the cranial cavity. This problem if further confounded by the dished forehead found in some breeds and prominent ridge in mature pigs (boars and sows). However, the ideal shooting position is 20mm above the eye level, on the midline of the forehead, aiming towards the tail (Humane Slaughter Association, 1998; visit www.hsa.org.uk for details). The muzzle of the captive bolt stunner must be placed firmly against the head.

The signs of effective captive bolt stunning are that the animal collapses immediately, stops breathing, its head extended and hind legs rigidly flexed towards the abdomen. The fore legs may be flexed initially and then gradually straighten out. This period of rigidity (tonic phase), usually lasting for 10 to 20 seconds, is followed by a period of paddling or kicking movement. Pigs stunned with captive bolt must be bled out immediately.

4. Killing of pigs on the farms during disease outbreaks

Outbreaks of notifiable diseases (e.g. swine fever) require prompt and stringent disease control and eradication measures to safeguard health and welfare of animals. Under normal circumstances, during the outbreaks of notifiable diseases, authorities entrusted with the responsibility for killing large numbers of animals would select killing methods on the basis of animal welfare, its feasibility, operators' health and safety and biosecurity, at the least. Various methods of killing pigs for the purpose of disease control and their advantages and disadvantages are presented in detail in the EFSA scientific report (EFSA, 2004; www.efsa.eu.int/science/ahaw/ahaw_opinions/495_en.html).

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Chapter 9. Breeding pigs for improved welfare

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Abstract

Selection is a very powerful tool to improve production and reproduction, but selection for these traits has been shown to be potentially detrimental to traits important for welfare of pigs. One example of such a negative side effect is the Porcine Stress Syndrome (PSS). The frequency of the allele causing this syndrome increased during the 1970s, as an effect of the selection for leanness. Selection is, however, a powerful tool to improve traits important for welfare. Many welfare related traits have low heritability, which has the implication that a high number of recordings are needed to reach a good accuracy in the selection process. Examples of such traits are: piglet survival, maternal behaviour, fear, the sow's ability to produce milk and to use body reserves, improved resistance to harmful micro-organisms, aggressive behaviour and tail biting. Crossbreeding reduces the risk of defects related to welfare, since many defects are caused by single, mutated genes with a recessive inheritance. To a degree, natural selection also improves animal welfare within current breeding programmes. Individuals that do not survive, have inferior constitution or are more susceptible to diseases are less likely to become parents. We propose that the current breeding programmes should be expanded to incorporate the following selection traits: improved piglet survival, stronger legs and better constitution. From a long-term perspective, we propose that selection should also be made for: improved disease resistance, less aggressive behaviour, reduced fear of humans and greater appetite.

Keywords: selection, welfare, breeding goal, negative side effects

1. Introduction

To breed animals is to change animals – to alter the characteristics of new generations of animals by selection. Genetic change can have a significant impact on animal welfare and unlike changes brought about by feeding or management, these changes are persistent and may last through many generations. Thus, geneticists and pig breeders need to take their responsibility for the welfare of today's and tomorrow's pigs seriously.

The domestication of the pig started approximately 10,000 years ago, separately in Asia and Europe (Giuffra *et al.*, 2000). Since then the animal has developed from a small wildboar sow giving birth to a litter of between five and seven slow-growing fat pigs once a year to today's large sow, which produces more than 20 fast-growing lean pigs a year. Even though an increasing quantity of animal products continues to be required (FAO, 1999), we do not necessarily need more animals around the globe. Indeed growing numbers of animals will increase environmental pollution and energy consumption. What we need instead are efficient animals, and we can achieve this through breeding programmes. Genetic progress in production traits during the last decades has been enormous. Litters are larger, the pigs grow faster, the carcasses are leaner and less feed is needed. A rough estimate of the genetic change during the last 40 years in many pig populations is: +8%-units in carcass leanness and -70 kg feed/fattening pig. Today we thus produce 1000 kg lean meat from 20 pigs instead of the 23 pigs needed 40 years ago, and in doing so we use approximately 2000 kg less feed.

Breeding programmes aiming at high levels of production reduce the negative environmental impact of pig production by securing more effective conversion of feed to lean meat (Fernández *et al.*, 1999). However, such breeding can also threaten animal welfare. Rauw *et al.* (1998) report more than 100 references to the negative side effects of selection for raised productivity. In their review, undesirable correlated effects in metabolism, reproduction and health traits are identified in broilers, turkeys, pigs and dairy cattle.

Drawing on genetic theories, we can predict that current selection will increase unfavourable genetic correlations between traits in successive generations. Fortunately, the same genetic rules that result in the negative side effects of selection for increased production (and thereby decreased animal welfare) can be used to improve animal welfare. Welfare is, of course, not a biological trait or a characteristic of the animal. There are no welfare genes. It is, however, possible to select animals for e.g. increased disease resistance with the aim of improving welfare. With well designed breeding programmes, we can avoid the negative side effects of selection for production. In addition to selection aimed at reducing negative side effects, we can directly improve traits important for animal welfare regardless of their relation with production traits.

2. Genetics and animal breeding

All pigs are individuals. Each performs and behaves differently. Part of this variation is explained by the environment, e.g. feeding norm or number of pigs per pen. But the variation is also due to genetic differences between animals, all pigs are genetically unique. Genetic variation is the basis of all genetic change. This is true both when the change appears in nature (natural selection) and when it occurs as a result of planned human decision (selection in a breeding programme).

Genes have two purposes: to regulate all processes in the body and to forward information from one generation to the next. Collectively, an animal's genes – the sum total of its genetic information – make up a 'genome'. The genome is built of DNA sequences which are (so to speak) packaged in chromosomes. In each cell there are two copies of each gene, or two alleles. One allele originates from the mother and the other from the father. If the two alleles are different, the animal is called a heterozygote with regard to this gene. If they are the same, the animal is a homozygote. Some animal characteristics are governed by single genes. Such characteristics are known as 'qualitative traits'. Many coat colours are like this, for example. Another, well-known example is the dominant allele for brown eyes in humans. A child has brown eyes even if it has received the brown eye-colour allele from only one of its parents. Most alleles for genetic defects are recessive. This means that two alleles coding for the defect (one from the mother and one from the father) are needed to produce the animal defect. Porcine Stress Syndrome (PSS) is caused by a mutation in the gene coding for muscle ryanodine receptors. This mutated allele is recessive (Fujii *et al.*, 1991).

Once favourable alleles have been identified, animals can be selected using molecular analysis of DNA from blood or hair samples; and even when the gene coding for the relevant characteristic is not identified, DNA analyses can be helpful. Part of the pig genome has been mapped, i.e. its DNA sequence is known. This does not mean that we know the function of all the genes. Nevertheless, information from the gene map can be used to find animals with wanted characteristics. Some parts of the DNA sequence show a large variation between individuals. If a certain DNA sequence is found to be related to an important characteristic (e.g. resistance to a disease), pigs carrying that sequence can be selected. Geneticists call such identified DNA sequences 'markers' and talk about marker-assisted selection. The idea with marker-assisted selection is that the marker can be used to select pigs carrying a favourable allele, although the gene coding for the characteristic itself has not been identified.

In many genes, the alleles are neither dominant nor recessive. The expression of such a gene will be a mean of the two alleles. So, if the allele from the mother codes for a low production of a certain enzyme and the allele from the father codes for a high production, the result will be an average enzyme production. But most traits are regulated by many different genes, the effect of each gene on the trait being modified by the effects of a number of others. Such traits are said to have a quantitative genetic background, and here geneticists talk about the additive genetic effect. Growth rate, disease resistance, leg weakness and maternal behaviour are all examples of quantitative traits. An animal's genotype is an average of all alleles influencing these traits. But we can never observe the genotype. What we see is the phenotype, and this results from the genotype *and* the environment. Although the environment has a significant influence on the animal, it is not inherited. Indirect identification of the genotype is thus fundamental in animal breeding.

If a large part of the variation in a trait (such as constitution) is related to the animals' genotypes, it is rather easy to improve the trait by selection. If a large part of the variation is caused by environmental factors, it is much more difficult to find the animals with the best genotype. Geneticists call the inherited genetic part of the total variation the 'heritability' of a trait (h^2). A high-heritability trait, like leanness, is easy to change with breeding. A low-heritability trait, like disease resistance, is difficult to change. Heritability estimates range from 0 (only environmental influence) to 1 (no environmental influence).

Traits that are partly regulated by the same genes (or genes situated nearby on the chromosome) follow each other. Such a relation is called a genetic correlation (r_g) and is described with values from -1 via 0 to +1. With a negative correlation, one trait increases when the other decreases; with a positive correlation both traits are changed in the same direction. Breeding for increased growth rate leads to improved feed efficiency; there is a favourable genetic correlation. But traits promoting welfare can also be altered when animals are selected for enhanced production. Thus breeding for increased growth rate leads to increased leg weakness; there is an unfavourable genetic correlation. To reduce the risk of negative side effects of selection, the breeding goal should be composed of production, reproduction and health traits. Traits that are important for welfare should be recorded, together with the production traits.

A breeding programme is built on several steps. The first step is to decide the breeding goal. That goal might be fast-growing and healthy pigs with a tasty meat. The heritabilities of the traits included in the breeding goal must be estimated, as well as their genetic correlations. If the heritability of a trait is very low, it may be better to invest in improvements to the pigs' environment, i.e. changes in management and housing. The next step is to record the traits (growth rate, diseases, meat quality) together with animal identities and pedigrees. All this information is gathered in a database and used in a genetic evaluation to estimate animals' breeding values. The breeding value predicts how much of an animal's result will be inherited by its offspring, e.g. 25 g/day faster daily gain (compared to the population mean). The best animals, those with the highest breeding values, are then selected to become parents of the next generation. Thanks to the database, which covers all the relationships between animals, it is also possible to estimate the breeding value of animals without their own records. Thus, a boar can have a breeding value for maternal ability, although obviously that trait can be recorded in sows only. The accuracy of the breeding value depends on the amount of information in the database. Especially for traits with low heritabilities, such as most health traits, it is important to collect many records. Some traits (like the maternal ability of sows) can be recorded several times in the same animal; others (like leg weakness scores on fattening pigs) are recorded just once but in many animals.

When several traits are included in a breeding goal, an optimal combination of these traits is sought. The weight given to each trait in the genetic evaluation depends on heritabilities, on the correlations between the traits, and on the economic value of a change in each of these traits. Such weighting factors are called economic weights in animal breeding.

In pigs, most genetic change has been achieved by breeding programmes based on quantitative genetics. In the future, molecular genetics will have a larger influence on the breeding work. The possibility of working with marker-assisted selection and identified single genes has been described above. Another expression used in modern genetics is 'quantitative trait loci' (QTL). A locus (plural *loci*) is a position on the chromosome where a gene is located. QTL is a region of the DNA sequence that is found to have a significant effect on a quantitative trait, e.g. litter size or leanness. Although such traits are governed by many genes, as mentioned above, some of these genes may be more important than others. QTL can be useful even if none of the genes influencing the trait of interest have been identified.

3. Pig breeding today

Breeding values for production traits (growth rate, carcass leanness and feed conversion), reproduction (mostly recorded as litter size at birth) and in some cases also constitution, are combined with their economic weights to create total breeding values. Most selection is based on these values. Pig breeding has a hierarchical structure. Genetic evaluation and selection is performed in a limited number of nucleus herds with purebred animals. In these herds, thorough recording schemes are applied, and the records accumulated are the basis of subsequent genetic evaluation. Genetic progress achieved in the nucleus herds is disseminated to pig production as a whole mainly via artificial insemination (AI). The AI-boars are born in the nucleus herds, selected and taken to AI-stations, from where the semen is sold to commercial farmers. Genetic progress in the nucleus herds is also transferred to commercial herds via females. Purebred gilts are sold to multiplier herds, where crossbred gilts are produced and sold to the commercial farmer; or crossbred gilts are produced in the nucleus herds and sold on directly. All pigs raised for slaughter in commercial herds are crossbred. The father of these pigs comes from a sire line (sire breed) and the mother is a cross between two different dam lines (dam breeds). The aim in crossbreeding is to foster hybrid vigour or 'heterosis'. In a trait with a pronounced heterosis effect, the result of the offspring is better than the average of its parents' results. This is the case for many traits that are important for welfare, such as piglet vitality and disease resistance.

Before today's computerised genetic evaluation tools became available (in the 1970s), the only way to compare the genetic capacity of animals from different nucleus herds properly was to test them at a central testing station. However, with the evaluation techniques available today, and because the genetic links between herds are now strong (due to the frequent use of AI), station testing has become less important. Increased use of AI has also led to reduced transfer of live animals between herds at all levels of the breeding pyramid; and this in turn has reduced the spread of many infectious diseases. Therefore, AI is not only an important tool in animal breeding; it may also improve animal health and thus welfare. High health status in nucleus herds leads to increased heritability for many traits, since the environmental influence is then lower. On the other hand, natural selection promoting improved resistance to infectious diseases might be less vigorous when the infection pressure is very low.

4. Direct influence of breeding procedures on welfare

Can recording influence the welfare of pigs in nucleus herds? Most of the management routines linked with the breeding activities differ little from those in commercial pig production. Recordings are mainly of general herd-monitoring character, focusing on such matters as dates of mating and farrowing, litter sizes at birth and weaning and body weights on particular occasions or at certain ages. In addition, ultrasonic backfat measurements (often called performance testing) are performed in the nucleus herds; and in some breeding programmes, blood samples are taken to monitor health, to identify certain alleles or to check an animal's identity. Ultrasonic testing and weighing do not hurt the pig, even though the handling associated with them can be stressful if the routines are poorly designed or badly executed. The transportation of pigs to a testing station where they are mixed with unknown pigs may also be stressful. Another potentially weak point is the mixing of pigs from different herds, which leads to a high infectious pressure and sometimes to outbreaks of disease at the station. Finally, at many modern testing stations, the pigs are fed in electronic feeders where only one pig can eat at a time – a departure from the pigs' natural social behaviour at feeding.

5. Heterosis improves piglet vitality

Piglet vitality is a very important trait in pig production. Today, almost two piglets in each litter are lost on average; and it can be assumed that death is often painful for the piglet. Thus, piglet mortality is not only an economic issue, but also a welfare issue. Stillbirth, crushing by the sow and starvation are the most common causes of piglet death. Most of the piglets lost after birth die during the first days of life (see Chapter 4).

Few breeding programmes include piglet survival as a selection trait. Almost all pig production is, however, based on cross breeding. Improvements brought about by heterosis are important for litter size and for piglet survival. Heterosis improves piglet survival on two levels. First, the dam is a two-breed cross, e.g. Large White × Landrace. Secondly, the piglet often has a sire of a third breed, e.g. Duroc or Hampshire. Litters of crossbred dams have on average a 5% higher survival rate between birth and weaning; and crossed piglets have on average a 6% higher survival rate from birth to weaning (Rothschild and Bidanel, 1998).

Inbreeding, which brings about the opposite of heterosis, increases the risk of genetic defects. Most genetic defects result from recessive alleles. Thus, they will only appear if the animal is homozygous, i.e. if the animal has got alleles coding for the defect from both its mother and its father. In an inbred population, genetic variation is low (the animals share more genes) and therefore the risk of inheriting the same defect allele from both parents increases. The genetics of common defects in pigs is not yet fully understood. Some defects are probably ruled by single genes; others seem to have a quantitative genetic background. A catalogue of inherited disorders is accessible on the internet as Online Mendelian Inheritance in Animals (OMIA, http://omia.angis.org.au/). According to OMIA, a number of genetic defects in the pig are caused by single genes, e.g. tremor, leglessness and absence of skin areas. Most, however, seem to have quantitative genetic background. Low to intermediate heritabilities have been estimated for several malformations, including splay legs and scrotal hernia (Beissner *et al.*, 2003).

Regardless of whether the malformation has a quantitative or qualitative genetic background, it is essential for data on malformed piglets to be collected in the breeding scheme. AI-boars with a high proportion of malformed piglets should be culled as early as possible. For practical reasons, some AI-organisations sell semen that is a mixture from several boars, but with mixed semen it is difficult to identify the AI-boars carrying alleles for defects. In this way an AI-boar that should have been culled can remain undetected for a long time and transmit a defect allele to many herds. Preferably, AI-boars should be used in test matings before their semen is introduced on the market, but test mating is costly and time consuming. Chromosome aberration provides another reason to check the AI-boars before large-scale use of semen. Chromosomal aberrations can be identified by a simple laboratory test. In the genome of boars with so-called 'balanced reciprocal translocations', small pieces of DNA have been exchanged between two chromosomes. The number of known chromosome translocations is steadily increasing and is at present around 100 (Gustavsson, personal communication). Such translocation generally results in small litters, and sometimes in malformations increasing postnatal mortality (Gustavsson and Jönsson, 1992; Villagomez *et al.*, 1995).

6. Selection for increased litter size requires selection for piglet survival

Selection for increased litter size has been very successful in many countries. In fact, progress has been so good that farmers sometimes regard large litters as a problem. The main negative side effect of selection for increased litter size is decreased piglet survival. But piglet survival is heritable, and although the heritability is low, it is not lower than the heritability for litter size. Thus, piglet survival can and should be increased by selection. To understand the genetics of piglet survival, we need to study both direct and maternal genetic effects (Grandinson, 2003). A direct effect of the piglet's own genes might, for example, be its ability to find a teat and to suckle. A maternal effect of the sow's genes might be the sow's ability to produce colostrum. Generally, maternal effects have a greater influence on piglet survival than direct effects (Lund *et al.*, 2002). Unfavourable genetic correlations between these two have been reported (Van Arendonk *et al.*, 1996). This complicates the selection process: should we aim for good mothers or vital piglets? But the genetic correlation is not very strong, so it is possible to include both the direct (the piglet itself) and the maternal effect in the genetic evaluation to make progress in both traits.

Several selection experiments have shown that selection for lean carcasses or high lean tissue growth rate leads to higher piglet mortality (Vangen, 1980; Kerr and Cameron, 1995). The selection of pigs with a genetic capacity for rapid growth may also have an unfavourable effect on piglet survival (Knol, 2001; Grandinson *et al.*, 2005). Herpin *et al.* (1993) compared piglets from different breeds and concluded that selection for higher lean tissue growth rate results in less developed piglets at birth. In short, then, the current selection for leanness, growth rate and litter size provides a strong motive for including piglet survival in the genetic evaluation.

Birth weight is phenotypically associated with survival, since the smallest piglets have an increased risk of dying (Roehe and Kalm, 2000). It has therefore been suggested that piglet survival rates can be improved indirectly through selection for high birth weight. Birth weight is easier to handle in genetic evaluations, because it is a normally distributed trait (unlike survival, which is binary: dead or alive), and because it has higher heritability. According to a genetic correlation estimated by Grandinson *et al.* (2002), selection for increased birth weight results in fewer crushed piglets (r_g=-0.5). Despite these encouraging signs, any attempt to improve piglet survival by increasing birth weight is likely to be problematic. Grandinson *et al.* (2002) have also found a genetic correlation between birth weight and stillbirth: selection for increased birth weight would result in more stillborn piglets.

7. Maternal behaviour and fear

The maternal behaviour of the sow is an important factor in piglet survival and growth, and thus in piglet welfare (Bergeron *et al.*, Chapter 3). Behavioural traits are, however, difficult to record on a large scale, and consequently there are only few genetic studies of maternal behaviour. Some sows are aggressive towards their newborn piglets, especially at first farrowing. Marchant Forde (2002) showed that sows displaying high levels of fear of humans savaged their piglets more often. In some lines, as many as 10% of sows are reported to injure or kill piglets. This unwanted behaviour has a genetic background, and its heritability is rather high (h^2=0.4; Knap and Merks, 1987), so animals should never be selected from litters whose mothers show aggressive behaviour. Here natural selection provides assistance, since there are often no piglets alive to select in those litters.

Crushing by the sow is one of the most common causes of piglet mortality. In most countries, the sow is kept in a crate, to prevent crushing. Since this is stressful for the sow (see Bergeron *et al.*, Chapter 3) we have to find alternative ways to prevent crushing. Selection for improved maternal behaviour is one alternative. Improved maternal behaviour would also make it easier to achieve high piglet welfare when sows are farrowing outdoors. The sow's reaction to a screaming piglet has been recorded in field studies by Grandinson *et al.* (2003) and Løvendahl *et al.* (2005). The heritability is low (h^2< 0.1), not unlike heritability for piglet survival. Grandinson *et al.* (2003) found a genetic correlation between sow reaction and piglet survival: the stronger reaction was associated with higher survival (r_g=0.2). In the Grandinson study, farmers also recorded the sows' fear of the farmer. Here heritability was around 0.1, and there was a genetic correlation with piglet survival: less fear was associated with higher survival (r_g=-0.4). The sows' reaction in a scream test, or the sows' fear of humans, could therefore be used in breeding programmes aiming for improved piglet welfare when sows are loose-housed. The environmental influences on these traits are, however, very considerable, and therefore their heritabilities are low. Any genetic progress will consequently be slow. Questionnaires in which the farmers summarise their observations of the sows' behaviour could be used instead of behaviour tests. Such questionnaires have been used in a Nordic project on the maternal behaviour of sows (see www-NordicNetworkSow.slu.se). The heritability estimates for sow behaviour seemed slightly higher when they were based on questionnaires than they did when they were based on the tests described above. For example, the heritability of sow's fear of the farmer during management was estimated at 0.2 (Vangen *et al.*, 2005).

Selection for reduced fear is desirable not only because it would improve piglet survival rates but because it has its own welfare value. Freedom from fear is one of the five freedoms included in a common definition of animal welfare (Farm Animal Welfare Council, 1992). Hemsworth *et al.* (1990) estimated moderate heritability of fear of humans in gilts (h^2=0.4). Fearfulness has been shown to be heritable in many species, and the effect of fear on welfare and production has been discussed by Vandenheede (1996) among others. The accuracy of a genetic evaluation increases with the amount of information. Sows give birth to large litters and therefore there are relatively few sows in a nucleus population. Moreover, the sow is one year old before it farrows. The fact that there are few records, recorded late in life is a weakness in any selection programme. But it is possible to record the pig's fear of humans in both sexes and at a young age. This information from young males and females can be used in the genetic evaluation of breeding sows. Consistent differences between individuals in stress reactivity are described in Chapter 2. Correlations between fear measured at different ages and in different situations must, however, be estimated, since fear is a very complex trait (Janczak, 2002). There is, probably, an ongoing selection against fear at the herd level, but no genetic evaluation of fear has been used in any pig breeding programme that we know.

8. The sow's ability to produce milk and to use body reserves

Starvation is a common threat to piglet welfare. The piglet is born with very small body reserves and immediate colostrum intake is essential for its survival. In sows there is considerable variation in colostrum production (Devillers, 2004). Colostrum production can be recorded as piglet growth, from birth to 24 hours of age. It would be very interesting to estimate the genetic variation of this trait.

The replacement of colostrum by milk is initiated a few hours after farrowing. Breed differences in milk production and milk composition have been reported by Grün *et al.* (1993). These authors and Mersmann *et al.* (1984) propose that selection for leanness decreases the nutritional quality of sow milk. Ideally, the sow should be able to produce a large quantity of milk of high quality and it should also be able to serve that milk to the piglets in an effective way. The more often a sow nurses the piglets the better they grow, and there are individual differences in nursing frequency between sows (Valros *et al.*, 2002). The sow's motivation to nurse could also be important for piglet welfare, especially when sows and piglets are loose-housed in groups or on pasture. Thodberg and Jensen (2005) have shown how nursing motivation can be tested, but so far we possess no genetic studies on nursing behaviour.

Current selection for larger litters increases the demands made on the sows by piglets during lactation. Sows with a genetic capacity for high piglet survival and growth rate lose more weight during lactation (Grandinson *et al.*, 2005). Most sows have to use their body reserves during lactation to produce milk for their piglets. Strong selection for lean carcasses has, however, decreased sows' fat reserves. In many breeding programmes in which young pigs have been selected for leanness while fed ad libitum, appetite has decreased. Pigs with a low feed intake stay lean even when fed ad libitum; thus pigs with smaller appetites have been selected. However, lactating sows need a very good appetite. A sow with 12 piglets produces approximately 12 litres of milk per day. To do that it needs to eat more than 7 kg sow feed – this is in addition to the feed she needs for her own maintenance. The voluntary feed intake of most sows is below this figure, especially in hot climates. Van Erp *et al.* (1998) have estimated the heritability for voluntary feed intake in lactating sows at 0.2 in a small study. They have also reported a high genetic correlation between voluntary feed intake during the growth phase and during lactation (r_g=0.9). Eissen *et al.* (2000) recommend selection for higher feed intake during lactation. Sows losing a significant amount of weight have an increased risk of shoulder ulcers and reproduction problems after weaning. An alternative selection trait would be weight-loss during lactation, which also has a heritability of 0.2 (Grandinson *et al.*, 2005).

In contrast with lactating sows, dry sows never get as much feed as they want. Their norm is usually less than 3 kg per day, but they will eat more if they are fed ad libitum. The genetic correlation between levels of appetite in different phases of the sow's life is not known. If we select for increased appetite during lactation, will dry sows become even hungrier? Freedom from hunger is an important factor in welfare, and sows spend more days out of lactation than in. The problem increases when sows are group-fed and so have to compete for feed. Here, low ranked sows will get even less than their already low feeding norm. Selection for increased appetite should therefore be complemented with improved management and feeding systems for dry sows – systems incorporating high quality straw, low concentration level of the feed and individual feeding stalls, for example.

9. Relations between growth, leanness, feed conversion and welfare

The primary breeding goal during the last 40 years has included fast growth, increased carcass leanness and improved feed conversion. Sometimes so-called 'conformation traits' have been included in the genetic evaluation, both as descriptors of lean meat content and as indicators of the constitution and vigour of the pig. This breeding for efficient meat production has led to some unwelcome outcomes. Porcine Stress Syndrome (PSS) is one such outcome, and genetic correlations have also been found between production and constitutional traits, such as leg weakness and osteochondrosis (Lundeheim, 1987; Jörgensen and Andersen, 2000) and between backfat thickness and carcass length. Leaner pigs have longer carcasses (r_g=-0.3; Lundeheim *et al.*,

1980) and in some breeding programmes, long carcasses are a goal. That might be beneficial when the focus is only on the amount of valuable cuts from the carcass, but might be detrimental to the functional constitution of the pig. Again, some breeding organisations have included an increase of the killing-out percentage in their breeding goal. In our opinion, this way ahead carries welfare and health risks. Pigs with a reduced proportion of internal organs may be less able to cope with physical efforts or stress.

Tail biting is a common problem among fattening pigs in some herds. No or very little bedding material is thought to be an important factor in this harmful behaviour. Hitherto, most preventive measures have been environmental or nutritional. The most extreme step is to cut off the tails of young piglets. Breuer *et al.* (2003) presented significant breed differences in a tail-chew test in which the pigs' biting behaviour towards a rope was recorded. Duroc pigs showed more biting behaviour than Landrace and Large White pigs. These authors also found that Duroc pigs ear-bite more frequently than Landrace pigs. Recently, Breuer *et al.* (2005) estimated a significant heritability for tail-biting behaviour (h^2=0.3) in Landrace, but not Large White, pigs. Both data gathered from a tail biting test and observed frequency of real tail biting are very time consuming to record. Even so, it might be necessary to collect these kinds of data in order to improve the welfare of fattening pigs, especially if there is a genetic correlation between tail biting and lean tissue growth rate, as proposed by Breuer *et al.* (2005).

10. Leg weakness and longevity

The reduced ability of pigs to move in what we regard to be a natural manner is generally called leg weakness. But this impaired function can be caused by a number of different weak points, from the quality of the horn of the claw, to weak joints, tendons and muscles. Leg weaknesses often cause stress and pain to the pig, and also impair the pig's ability to compete at the feeding through. Thus, leg weakness is related to several welfare factors. A number of studies have focused on the genetic background of clinical leg weakness recorded on growing pigs at testing stations (Lundeheim, 1987; Serenius *et al.*, 2001). Most of these traits are recorded in an all-or-nothing manner, or according to a scoring scale. This tells that there is a subjective recording influence on these traits. An increased environmental variation caused by different opinions among the technicians scoring leg weakness will decrease the heritability. Heritability estimates for leg weakness in general tend to be quite low. More specific leg weaknesses, such as buck-kneed fore legs, have higher heritabilities (Jörgensen and Vestergaard 1990; Serenius *et al.*, 2001).

One trait involved in the leg weakness complex is osteochondrosis. Osteochondrosis is a disturbance in the formation of bone from cartilage in the growing animal. The cartilage in the joint or in the growth plates grows as the pig grows, but the formation into bone tissue is disturbed. The cartilage becomes progressively thicker, and this increases the risk of deformation and painful crack formation. In the Swedish breeding programme, the frequency and severity of osteochondrosis has been recorded in pigs slaughtered in testing stations since 1982. From these data, osteochondrosis has been found to have a higher heritability than overall leg action (h^2=0.2-0.3, compared with 0.1-0.2; Lundeheim, 1987). The genetic correlations estimated between osteochondrosis, overall leg weakness and production traits are consistent with the widely held opinion that pigs with osteochondrosis and/or leg weakness problems have higher genetic capacity for growth rate and carcass leanness (Lundeheim, 1987). Yazdi *et al.* (2000) analysed the survival of purebred Swedish Landrace and Yorkshire sows, and found that the risk of early culling increased with genetic predisposition of osteochondrosis.

Improvement of the housing environment together with selection for functionally improved legs would increase pig welfare substantially. Such selection can be based on information from testing stations, on recordings made in connection with performance testing in nucleus herds, and on data on the causes of culling in sows. If genetic evaluation is based on information from a large number of animals, the accuracy of the selection can reach high levels in spite of the low heritability levels.

11. Selection against or for extreme stress sensitivity?

Porcine Stress Syndrome (PSS), which became more prevalent during the 1970s, afforded geneticists and pig breeders much general and specific knowledge, and in many ways acted as an alarm clock. Homozygous animals, i.e. animals with two copies of a recessive allele, coding for a defect muscle ryanodine receptor, have high stress sensitivity. Since these homozygous animals react with convulsions after halothane gas inhalation, this gene is often referred to as the halothane gene. The stress sensitivity leads to higher mortality when the animal is handled (especially in connection with transport to slaughter) and inferior meat quality (Murray and Johnson, 1998). The weights of liver, kidneys and spleen have been reported to be lower in PSS homozygous piglets than they are in heterozygotes (Nyström and Andersson, 1993). PSS is a good example of the way in which a genetic defect can reduce an animal's welfare through severe stress and death.

Intensive selection for leanness and the higher lean meat ratios in PSS homozygotes led to an increased frequency of the defect allele. Slaughter organisations learnt that the negative impact of the defect allele could be reduced by providing the pigs with a better environment (e.g. no electrical prods). Today this allele has, however, been eradicated in many pig populations. One might speculate as to whether it was the inferior meat quality and the increased death losses or the impaired welfare of PSS homozygotes that drove the eradication programmes, but it is clear that these programmes showed us how to use genetic markers in a selection programme. Some breeding organisations still regard the defect allele as favourable, since it makes the pigs leaner. In their breeding programmes, animals in the sire line are homozygotes with regard to the defect allele. Since the dam lines are free from this allele the pigs raised for slaughter will be heterozygotes and thus less affected by extreme stress sensitivity (Fernandez *et al.,* 2002). The welfare of animals in the sire lines can, however, be questioned.

12. Selection for improved resistance to micro-organisms

Without doubt, in most cases a pig affected by an infectious disease will not feel well. Generally, animals with low resistance to infectious disease will be selected less often as parents of the next generation, since infectious diseases reduce growth performance (Lundeheim, 1988). A number of studies have focused on the possibility of breeding for healthier pigs. Using post-mortem data on pigs from testing stations, Lundeheim (1979) found generally low heritability levels for respiratory diseases such as pneumonia and pleuritis ($h^2 \leq 0.1$). But data from a Danish testing station, analysed in a more sophisticated manner, showed somewhat higher levels of heritability (h^2=0.1-0.2; Henryon *et al.*, 2001). Rather high heritabilities have also been obtained for several physiological parameters reflecting immune competence in swine (Edfors-Lilja *et al.*, 1994). Magnusson *et al.* (1998) describe lines of pigs that were selected for high or low immune response, respectively. After four generations of selection the lines differed not only in the selection traits but also in what the authors refer to as 'real disease resistance'. The selection was based on humoral as well as cell-mediated immune response.

Disease resistance is a complex trait for which there is a great hope of finding QTL with significant effects. If such QTL (or even better, favourable alleles) are identified, it will be possible to select resistant animals on the basis of molecular analysis of blood samples. Sellwood *et al.* (1975) first described that pigs lacking the intestinal receptor for *E. coli* K88ac were resistant to diarrhoea caused by this serotype. Gibbons *et al.* (1977) demonstrated that there is a single gene with two alleles coding for the *E. coli* K88 receptor. Edfors-Lilja *et al.* (1995) showed that the K88 receptor gene is located on chromosome 13. A gene important for oedema disease and post-weaning diarrhoea has been identified by Meijerink *et al.* (2000). The gene regulates the activity of an enzyme involved in the adhesion of *E. coli* F18 in the small intestine. Today, both the

Danish and the Swiss breeding organisations are regarding information on single genes giving resistance to certain strains of *E. coli* (Hofer, 2005; Landsudvalget, 2005).

In most cases, disease resistance probably has a quantitative genetic background. However, animals are often recorded only as being sick or healthy. Our inability to record the level of disease resistance on an underlying, continuous scale explains why the estimated heritabilities are low, since much of the genetic variation is hidden. An alternative way to get higher heritabilities and thus faster progress would be to test pigs' resistance to certain diseases by giving each pig a vaccination dose. Then the humoral and cell-mediated immune response to that standardised infection could be measured. However, this higher heritability level would be much more costly to achieve than the sick-or-healthy approach to recording.

If genetic evaluation is based on information from a large number of animals, the accuracy of selection can reach high levels in spite of low heritability levels. Therefore, it is tempting to use post-mortem data from commercial slaughter plants in breeding for better health. It might, for example, be possible to collect the findings of meat inspections performed at the slaughter of commercial fattening pigs, and to trace this information back to the fathers of the slaughtered pigs. However, this approach requires the semen (the AI doses) to be identified, and that no mixing of boars has occurred at any stage, and that each pig is identified with its litter identity. It is also critical to this approach that we can be sure what the post-mortem data really show. If only acute cases of pneumonia are recorded at slaughter, pigs that were ill early in life will be classified as healthy and pigs that became ill at the end of the fattening period will be classified as sick. It is possible, however, that the pigs that were sick early in life were the ones with the lowest immune competence.

Most fattening pigs are crossbred, and in this way the beneficial effects of heterosis are secured. However, in crossbreeding schemes the additive genetic effect is still of the utmost importance. Lundeheim and Thafvelin (1986) reported significantly lower prevalence of respiratory diseases, abscesses and arthritis recorded after slaughter among the progeny of Hampshire boars than the progeny of Landrace and Yorkshire boars. In many regions of the world where swine production is intensive, antibiotics are commonly used as growth promoters and as a 'health insurance'. Besides the well-known problems associated with antibiotic resistance, intensive use of antibiotics masks the expression of genetic variation in disease resistance. This consequently reduces our ability to select for increased resistance to infectious agents.

13. Breeding instead of castration?

Male piglets are castrated in many countries to avoid the unpleasant smell of some entire-male (i.e. uncastrated) carcasses. Boar taint is mainly caused by two substances: androstenone and skatole. Androstenone is a steroid pheromone produced in the testis. Skatole is a product of bacterial tryptophane degradation in the hindgut. Male piglets are surgically castrated by the farmer in the first few weeks after birth without anaesthesia (see Chapter 4). The castration is painful (McGlone *et al.*, 1993) and so this practice has been questioned for welfare reasons. In Norway, castration will be prohibited by law from 2009. Until then, castration should be performed by veterinarians, using anaesthesia.

The level of both androstenone and skatole varies with age and between environments (Zamaratskaia, 2004), but there is also a genetic factor in boar taint. Not all entire male carcasses smell from boar taint, and breed variation has been reported by Babol *et al.* (2004). The heritability for skatole concentration has been estimated to 0.2-0.3 (Pedersen, 1998). It has also been suggested that a single gene has pronounced influence on skatole level (Lundström *et al.*, 1994). Thus, selection for reduced skatole levels could be included in breeding programmes, reducing the need for castration. There is also genetic variation in androstenone level, and androstenone concentration in fat is highly heritable (reviewed by Sellier, 1998). Androstenone is, however, a sexual pheromone and breeding for reduced sexual function carries risks. Indeed, Sellier and Bonneau (1988) showed that selection for reduced androstenone level in males genetically delayed sexual maturity in gilts. An alternative would be to select animals with certain alleles important for androstenone synthesis. Androstenone and testosterone are the products of two parallel chains in the testis which have pregnenolone as a common precursor. Cytochrome enzymes determine whether testosterone or androstenone is produced (Davis and Squires, 1999). If a QTL (or even better, an identified allele) that affects the choice between these two synthesis chains could be identified, animals producing testosterone rather than androstenone could be selected; and such selection would probably not deteriorate female reproduction traits. Another possibility could perhaps be to find a QTL advancing the ability of the liver to metabolise androstenone and skatole. Some major enzymes in androstenone and skatole metabolism in the liver have been identified (Doran *et al.*, 2003). The next step is to search for relevant QTL and to identify genes important for metabolism in the liver (Lin *et al.*, 2006).

The argument for the Norwegian ban on castration proceeded from concerns about animal welfare during and shortly after surgery. Castration may, however, improve other aspects of welfare. For example, entire males show more aggressive and sexual behaviour than castrates (Cronin *et al.*, 2003), and this could influence the health and welfare of all animals in the pen. Giersing (1998) showed that, in pens with both sexes, entire males are more frequently aggressive than gilts. In a study by Rydhmer *et al.* (2006), entire males in single-sex pens showed more sexual behaviour than those in mixed pens. A relatively large proportion of entire males had to be euthanised in that study, following leg problems (5 of 204 males) that may have been a consequence of aggressive and mounting behaviour. Mixing with unfamiliar pigs at slaughter caused more skin damage (scratches) when entire males were involved than it did when gilts were involved (Andersson *et al.*, 2005). The mixing of gilts and entire males at slaughter may also result in matings, even if the gilts are sexually immature (Andersson *et al.*, 1999). Selection against the ability to display sexual behaviour cannot, of course, be recommended, but selection against aggressive behaviour might be one way to improve welfare in entire males and their sisters.

14. Selection against 'bad behaviour'

Many sows are permanently confined in narrow stalls, although in several countries this is banned for welfare reasons (see Chapter 3). Loose-housed sows do, however, fight with one another, so loose housing sometimes improves average sow welfare at considerable cost to the welfare of small, young and low-ranking sows. This problem intensifies if sows are group-fed and thus compete for feed.

Janczak *et al.* (2003) and Ruis *et al.* (2000) found consistency, over time, in the aggressive behaviour of gilts. Studies of aggressive behaviour in newly mixed groups of sows have also shown that this trait is an individual characteristic of the animal (Jensen *et al.*, 2002). The social behaviour of an individual depends, however, not only on its own character but on the characters of group members as well. Thus, if aggressive behaviour is inherited, the social interactions in a group will depend on the genotypes of all the animals in that group (Moore *et al.*, 1997). In a Danish field study, farmers made observations of any aggressive interactions that occurred during the first 30 minutes when sows were mixed and housed in groups during pregnancy (Løvendahl *et al.*, 2005). The sows' backs were marked with numbers before the test, and both the aggressor and the victim of any attacks were noted. Aggressive behaviour was found to be a heritable trait (h^2=0.2), whereas being a victim had a heritability close to zero. It would be possible to test sows when they are group-housed after weaning or when being moved from the mating stall to the pregnancy stall. In a nucleus herd of 100 sows, approximately 12 sows are weaned every third week. One hour's work every third week would allow the farmer to mark the sows and record their aggressive behaviour. Given individual records of aggressive behaviour from the nucleus herds, the aggressive behaviour of sows could be included in the genetic evaluation and selected against.

Piglets are often mixed at weaning, and sometimes they are mixed again on entry to rearing facilities. Finally, they are mixed during transportation or at the slaughterhouse. Mixing is always stressful (see Chapter 7). It results in aggressive interactions and often also in injury. Individual differences in aggressiveness, recorded as attack latency time using resident-intruder tests, have been reported in young pigs (Erhard and Mendl, 1997). Busse and Shea-Moore (1999) found that pigs selected for high lean tissue growth rate were more aggressive during transport than pigs selected for low lean tissue growth rate. Social rank, recorded during feeding, had high heritability in entire males at a test station (h^2=0.5), and the genetic correlation between position in social rank order and growth rate was negative (r_g=-0.6; Jonsson and Jörgensen, 1989). Thus, selection for high growth rate could result in increased aggressiveness, as proposed by Schinkel *et al.* (2003). Muir (2005) has developed an elegant way to handle this unfavourable correlation without any need for behavioural observations. His model for genetic evaluation of growth rate includes the 'ordinary' direct genetic effect of an individual and the associative genetic effect, i.e. that animal's influence on the group members. With this approach, two breeding values are estimated for each animal, one describing the animal's genetic capacity for growth and the other describing the animal's genetic ability to influence the growth of other animals in the pen. Muir (2005) used the model in a selection experiment with Japanese quails that were restrictively fed. Genetic progress in the line selected for high growth rate with this model was much greater than it was in the line selected for high growth rate with an 'ordinary' animal model including only the direct genetic effect. Furthermore, mortality decreased in the first line and increased in the second line (Muir, 2005). The great advantage of this model is that it allows us to improve the welfare of animals raised in groups using data that are routinely available, i.e. records on the production trait and the identity of the group members (pen number and test period).

Selection for production seems to influence not only the social behaviour of animals but also the ease with which animals can be handled. According to Grandin (1991) extremely excitable pigs are an increasing problem in slaughter plants, the main impacts being on welfare and meat quality. The pigs are difficult to handle owing to their hyper-reactivity to touch, extreme flocking instinct and constant backing out of the single file race leading to stunning. Such pigs are likely to be handled with an electronic prod, which dramatically decreases their welfare (see Chapter 7). Line differences in ease of handling have been reported by Lepron *et al.* (2003) and Grandin (1991), and Grandin states that pigs selected for leanness are more excitable. In keeping with this, differences in stress response between the fat, slow-growing Meishan pigs and the lean, fast-growing Large White pigs have been found by Désautés *et al.* (1997). We have not found any genetic parameters for excitability or ease of handling in the literature, but Désautés *et al.* (2002) have detected QTL with strong effects on responses to novel environmental stress. Selection for lower stress reactivity would probably improve both welfare and meat quality.

15. Selection for decreased environmental sensitivity

Ideally, animals will be able to respond to changes in their environment, e.g. to altered climate and feed access. This ability to respond to environmental changes, which is called 'phenotypic plasticity' or 'environmental sensitivity', has a genetic background. When selecting animals for production, we generally create specialists, i.e. relatively non-adaptive individuals (Kolmodin, 2004). Selection for increased milk production will, for example, decrease heat tolerance in cows, since the genetic correlation between milk production and heat tolerance is negative (r_g -0.3; Ravagnolo and Misztal, 2000). Janczak *et al.* (2000) used mice as a model for pigs and compared a line selected for very large litters with a control line. Selection for large litters resulted in animals that performed well in their home environment, but were less able to cope with environmental change. Animals from the large-litter line showed more anxiety when tested in a new environment. These examples show that we should consider environmental sensitivity when selecting for high production.

What happens if we move pigs from one environment to another, e.g. from indoor to outdoor production systems, or from Northern Europe to the tropics? If pigs have low adaptability to environmental changes, welfare could be decreased. Kanis *et al.* (2004) recently presented a model for selection for low environmental sensitivity. Adaptation is based on behavioural and physiological mechanisms which bridge the gap between the pig's ideal situation and the actual situation. Kanis *et al.* (2004) used temperature as a model for the changing environment. When the gap between the ideal temperature and the actual temperature is small, the pig can dig into the straw or move to a cooler corner of the pen. When the gap is bigger, the pig tries to regulate body temperature by shivering or panting. Thus temperature becomes a stress factor and welfare is decreased. Kanis *et al.* suggest that potential breeding animals could be tested at test stations for their motivation to exchange a bad environment for a better one (e.g. to move from a cold or a hot climate to a temperate climate). Pigs with low motivation to exchange should be selected, since they have a greater ability to cope with extreme environments. In addition, pigs can be observed for their behaviour and physiological responses, and inferences about their welfare can be drawn. Such testing and selection would widen the temperature zone affording acceptable welfare for pigs, although it should be noted that the ethics of breeding pigs for an ability to cope with a 'bad' environment are debatable. Ethics of selection for decreased sensitivity have been discussed by Kanis *et al.* (2004), Knap *et al.* (2003) and Kolmodin (2004).

Today, much of the genetic swine material used in hot areas such as Asia and South America originates from international breeding organisations. If the same lines are to be used worldwide, selection for low environmental sensitivity will be useful. The alternative is to breed different lines for different environments, e.g. to push the temperature zone of the animals in the tropics towards higher heat tolerance. Ravagnolo and Misztal (2000) have shown that heat tolerance is inherited in dairy cows. Several pig breeding companies already market 'outdoor lines'. Similarly, heat tolerance could be included in a breeding goal to create 'tropical lines' that are better adapted to a hot climate.

16. More data are needed to improve welfare by breeding

Most traits important for welfare have low heritability. This means that a large amount of information is needed for genetic progress to be made on these traits. If selection is based on information concerning a large number of animals, its accuracy can be impressive in spite of low heritability. Since the number of animals in the nucleus herds at the top of the breeding pyramid is limited, it would often be helpful to have information on pigs beyond the nucleus, i.e. production animals. However, this would present a number of logistic challenges: it would be vital to track the identity and pedigree of each animal at all stages, to collect extensive data at herd level (covering such matters as medical treatments) and at slaughter (covering abscesses and the like).

The quality of the database is crucial in all breeding programmes. Today, our databases are full of records of body weight, growth rate, backfat thickness, carcass quality and litter size. Generally, however, records with a direct bearing on animal welfare – reason for culling, disease history, appetite, ability to cope with stress and various behaviours – are missing. This shortage of data not only limits our ability to select for traits that are important for welfare but also increases the risk of negative side-effects in current selection programmes. This is not to deny that there are cases, like the recording of osteochondrosis and piglet survival, where these difficulties have been largely dealt with.

17. The role of cooperation in improving pig welfare

Do we have the right to select for stress resistance? The ethical dilemma of animal breeding has been discussed in animal science and ethics (Sandøe *et al.*, 1999; Fraser, 2001; Kanis *et al.*, 2004). However, let us give an example: twenty years ago, when Porcine Stress Syndrome (PSS) was common, several slaughter organisations started campaigns for better animal welfare. Truck drivers and staff working at the slaughter plants were educated in animal welfare, and routines were changed. These improvements reduced mortality and increased meat quality. Welfare was thus increased, not only for pigs carrying the PSS allele, but for all pigs. We must be careful not to bring about the opposite of this, where we change animals genetically and attend less to their environment and management. It may be a good thing to breed plants for increased cold resistance, but breeding pigs that survive electrical prods is surely wrong.

Those who say that a trait is 'difficult to record' often mean that the trait is expensive to record. The inclusion of additional traits in a breeding goal inevitably results in slower progress in the production traits. Traditionally we use economic weights to identify the optimal combination of traits in a genetic evaluation. It is, however, difficult to calculate the economic weights of some traits important for animal welfare, e.g. stress resistance. Olsen *et al.* (2000) have shown how both non-market values and market values can be included in the genetic evaluation.

Obviously, animal breeding is always a long-term project. Thus, geneticists, nutritionists, ethologists, physiologists, veterinarians and pig producers need to cooperate, and to make joint use of all available knowledge, in order to:

- Improve pigs' environment and design good production systems.
- Design breeding programmes that create pigs that are well-adapted to these production systems.

After some years, we should:

- Evaluate the production systems and improve them.
- Modify the breeding programmes according to the results from the evaluation of the systems.

18. Practical implications

We have to admit that selection for production has created welfare problems. However, with wisely defined breeding goals, selection can also be a tool for improving the welfare of pigs. We propose that the current breeding programmes, which are mainly based on growth rate, leanness, feed conversion and litter size, should be expanded to incorporate the following selection traits:

- improved piglet survival;
- stronger legs;
- better constitution.

From a long-term perspective, we also propose that room should be made for the following selection traits:

- improved disease resistance;

- less aggressive behaviour;
- reduced fear of humans;
- greater appetite.

Finally, we suggest that economic weights used by most breeding organisations today should be replaced by more widely defined weightings that reflect not only short-term economic calculations but also longer-term benefits, including the welfare of the pigs.

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Chapter 10. Human-pig relationships

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Abstract

Research has shown that interactions between stockpeople and their pigs can limit the welfare and productivity of commercial pigs. While these interactions may appear harmless to the animals, this research has shown that the frequent use of some routine behaviours by stockpeople can result in pigs becoming highly fearful of humans. It is these high fear levels, through stress, that appear to limit pig welfare and productivity. One of the antecedents of stockperson behaviour is the attitude of the stockperson towards interacting with his or her animals. Intervention studies in the pig industry have shown the potential of cognitive-behavioural training designed to specifically target these key attitudes and behaviours of stockpeople. Other important human characteristics that will affect animal welfare and productivity include technical skills and knowledge, job motivation and commitment, job satisfaction and personality. Recent research in the pig industry has shown the value of not only measures of attitude but also some measures of motivation and commitment in predicting job performance. There is a clear need to reduce the limitations that human-animal interactions impose on the welfare of commercial pigs. It is likely in the near future that both the livestock industries and the general community will place an increasing emphasis on ensuring the competency of stockpeople to manage the welfare of farm animals. Appropriate strategies to recruit and train stockpeople in the pig industry will be integral in safeguarding the welfare of commercial pigs.

Keywords: human-animal relationships, attitude, behaviour, fear, stress, welfare

1. Human-animal relationships in pig production

The management of animals by humans is basically governed by two important principles and applies to a range of animal uses from individual pets to livestock production. These are, on the one hand, management to comply with the objectives of human profit, benefits or pleasure, and on the other hand, management responsibilities under a duty of humane care of animals. The latter is based on the widely-held view in our community that the use of animals by humans is acceptable provided that such use is humane.

Housing of farm animals is a contentious issue for many, although the impact of the housing system may be overestimated by some (Barnett *et al.*, 2001; Barnett and Hemsworth, 2003). The most frequently raised concerns about the welfare of domestic animals include confinement, indoor housing and routine husbandry procedures. In contrast to these concerns, the topic of stockmanship has received relatively little attention by the general public or the livestock industries, even though research has shown that animal carers or stockpeople have a major impact on the welfare of their livestock (Hemsworth and Coleman, 1998) and this is the topic of this chapter.

Human-animal relationships can be considered to be constructed from a series of interactions between humans and animals (Hemsworth *et al.*, 1992). The interactions by a human towards an animal may be tactile, visual, auditory, olfactory or gustatory and the nature of these interactions may be positive, neutral or negative for the animal. For example, fear-provoking interactions such as the sudden unexpected appearance of a human or a human looming over an animal may be negative for the animal, while painful interactions such as a hit by a human are obviously negative to animals. It is the nature of these human interactions that will markedly determine the quality of the human-animal relationship for the animal. The quality of the relationship for the animal can be assessed by measuring the approach behaviour or conversely the avoidance behaviour of the animal to the human in a standard testing situation. The relationships that exist between humans and farm animals in intensive livestock production are true relationships in that the interactions are frequent and often intense and, more importantly as considered later, the interactions can have reciprocal effects on the partners.

Research conducted in the pig industry has shown that human interactions can have surprising effects on the pig (Hemsworth and Coleman, 1998). While many of these interactions may appear mild and harmless to the animals, research has shown that the frequent use of some routine behaviours by stockpeople can result in pigs becoming highly fearful of humans. High levels of fear leading to stress have been shown to markedly limit the welfare and productivity of pigs. This research has also shown that a major antecedent of stockperson behaviour is the attitude of the stockperson towards interacting with his or her animals. A model of these human-animal relationships in the intensive livestock industries is presented in Figure 1.

There is a number of well-recognised job-related characteristics of the stockperson that are likely to affect the work performance of the stockperson and, in turn, affect animal welfare and productivity and these characteristics include technical skills and knowledge, job motivation and commitment and job satisfaction (Hemsworth and Coleman, 1998). Furthermore, human-animal interactions may directly affect a number

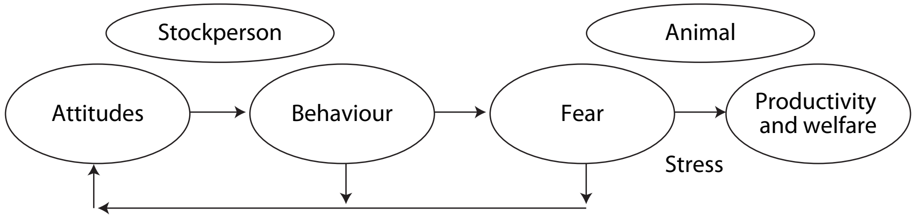

Figure 1. A simple model of human-animal relationships in the intensive livestock industries.

of these job-related variables and consequently influence the work performance of the stockperson and, in turn, the welfare and productivity of the animal.

The aim of this chapter is to review the impact of these human-animal interactions on the welfare of commercial pigs and consider some of the opportunities that exist to reduce the limitations imposed by these interactions on pig welfare.

2. Fear, productivity and welfare

There appears to be considerable between-farm variation in the fear response of animals to humans in the livestock industries, including the pig industry (Hemsworth and Coleman, 1998). Fear is generally considered an undesirable emotional state of suffering in both humans and animals (Jones and Waddington, 1992) and one of the key recommendations proposed to the United Kingdom Parliament by the Brambell Committee in 1965 (Brambell *et al.*, 1965) was that intensively-housed livestock should be free from fear and there are several reasons why fear of humans will reduce the welfare of farm animals. Research has shown that farm animals that are both highly fearful of humans and in regular contact with humans are likely to experience not only an acute stress response in the presence of humans but also a chronic stress response that is evident even in the absence of humans (Hemsworth and Coleman, 1998). Fearful animals are also more likely to sustain injuries trying to avoid humans during routine inspections and handling. Furthermore, in situations where human contact is aversive, the stockperson's attitude towards the animal is likely to be poor and thus the stockperson's commitment to the surveillance of and the attendance to welfare (and production) problems facing the animal may be deficient. Clearly, fear in farm animals can impact on farm animal welfare and thus this topic of how farm animals are handled is a legitimate welfare consideration.

A particularly important result that stimulated considerable research over several decades on human-farm animal interactions was the finding of a negative correlation between fear of humans, as assessed on the basis of the behavioural response of commercial pigs to humans, and the reproductive performance of commercial pigs. As shown in Table 1, observations in the Dutch and Australian pig industries revealed significant negative correlations, based on farm averages, between fear of humans and reproductive performance of pigs. The direction of the relationships indicate that reproductive performance was low at farms where breeding females were highly fearful of humans and the magnitude of these relationships indicate that variation in fear of humans accounted for about 20% of the variation in reproductive performance across the study farms. In contrast to farms in the first study, farms in the second study varied substantially in terms of size, housing systems, genetics, nutrition and locality and yet significant fear-productivity relationships were found, which demonstrate the robustness of the fear-productivity relationship in the pig industry. Similar negative fear-productivity relationships have been found in the dairy and poultry industries (Barnett *et al.*, 1992; Breuer *et al.*, 2000; Cransberg *et al.*, 2000; Hemsworth *et al.*, 1994b, 2000).

Handling studies and observations on stockpeople in the livestock industries have shown that farm animals, including pigs, are surprisingly sensitive to brief handling by humans. While it is easy to appreciate that regular negative interactions with animals, particularly painful or very aversive negative interactions such as hits or shocks with a battery-operated prod, will produce high fear responses to humans, farm animals have been shown to be sensitive to brief human interactions of an intuitively minor nature. For example, fast and unexpected movement and close approach by humans are fear-provoking for dairy cattle, pigs and poultry (Gonyou *et al.*, 1986; Hemsworth *et al.*, 1981a, 1986, 1987, 1996a; Hemsworth and Barnett, 1991; Paterson and Pearce, 1989; Pearce *et al.*, 1989). For many animals, particularly cattle, shouting by humans is fear-provoking (Waynert *et al.*, 1999; Breuer *et al.*, 2000; Pajor *et al.*, 2000). In contrast, positive handling, such as patting or stroking pigs or talking to pigs when the opportunity arises, lowers fear levels (Gonyou *et al.*, 1986; Hemsworth *et al.*, 1981a,

Table 1. Fear and productivity correlations in the pig industry.

Pig industry	Fear[1] and productivity
Hemsworth *et al.* (1981b)	-0.51*
Hemsworth *et al.* (1989)	-0.55*

*Significant correlations (P< 0.05) indicate associations between the two variables.
[1]Fear of humans by pigs was assessed by the time spent near a stationary experimenter and the productivity variable was the number of piglets/sow/year.

1986, 1987, 1996a; Hemsworth and Barnett, 1991; Tanida *et al.*, 1995). Understanding the sensitivity of pigs to human contact is obviously critical in handling animals in a manner that minimises their fear responses.

Negative tactile interactions imposed briefly but regularly on pigs, not only results in high levels fear of humans, but also may markedly reduce the growth and reproductive performance of pigs. A summary of some of the results of these handling studies is presented in Table 2.

Table 2. The effects of handling treatments on fear, stress physiology and productivity of pigs in six studies.

Experiment and parameters	Positive treatment	Minimal treatment[1]	Negative treatment
Hemsworth *et al.* (1981a)			
Time to interact with human (s)[2]	119	-	157
Growth rate (11-22 weeks in g/day)	709	-	669
Cortisol concentrations (ng/ml)[3]	2.1	-	3.1
Gonyou *et al.* (1986)			
Time to interact with human (s)[2]	73	81	147
Growth rate (8 – 18 weeks, g/day)	897	881	837
Hemsworth *et al.* (1986)			
Time to interact with human (s)[2]	48	96	120
Pregnancy rate of gilts (%)	88	57	33
Cortisol concentrations (ng/ml)[3]	1.7	1.8	2.4
Hemsworth *et al.* (1987)			
Time to interact with human (s)[2]	10	92	160
Growth rate (7-13 weeks, g/day)	455	458	404
Cortisol concentrations (ng/ml)[3]	1.6	1.7	2.5
Hemsworth and Barnett (1991)			
Time to interact with human (s)[2]	55	-	165
Growth rate (from 15 kg for 10 weeks in g/day)	656	-	641
Cortisol concentrations (ng/ml)[3]	1.5	-	1.1
Hemsworth *et al.* (1996a)			
Time to interact with human (s)[2]	52	79	145
Growth rate (from 63 kg for 4 weeks in kg/day)	0.97	1.05	0.94
Adrenal weights (g)	3.82	4.03	4.81

[1]Treatment involving minimal human contact.

[2]Standard test to assess level of fear of humans by pigs.

[3]Blood samples remotely collected at hourly intervals from 08:00 to 17:00 h.

The mechanism responsible for the adverse effects of high fear on the productivity of pigs appears to be a chronic stress response, because handling treatments which resulted in high fear levels, also produced either a sustained elevation in the basal free cortisol concentrations or an enlargement of the adrenal glands, together with depressions in growth and reproductive performance (Barnett *et al.*, 1983; Table 2). It is well known that the long-term activation of the hypothalamic-pituitary adrenal axis can have marked effects on efficiency of growth with for example the catabolic effects of ACTH and corticosteroids (Elsasser *et al.*, 2000). Corticosteroids also support the synthesis and action of adrenalin in stimulating glycogenolysis and lipolysis (Matteri *et al.*, 2000). Stress-induced changes in the secretion of pituitary hormones have been implicated in failed reproduction (Clarke *et al.*, 1992; Moberg, 2000).

3. Stockperson characteristics regulating the pig's fear of humans

In an attempt to identify the stockperson characteristics affecting fear of humans in commercial pigs, Coleman *et al.* (1998) and Hemsworth *et al.* (1989) studied the attitudes and behaviours of stockpeople towards their pigs. An attitude questionnaire was used in these studies to obtain information on the behavioural beliefs of stockpeople about interacting with pigs. The attitude questionnaire was in two parts: the first half contained a series of belief statements about characteristics of pigs and the second half contained statements about interacting with pigs. The nature of the behaviour of stockpeople towards their pigs in these two studies was observed during routine mating activities such as moving pigs for mating, conducting oestrus detection and assisting pigs to mate. Negative tactile behaviours by stockpeople that were recorded included forceful hits, kicks and slaps (highly negative) and audible slaps and pushes (moderately negative), while positive tactile behaviours included pats, strokes and the hand of the stockperson resting on the back of the animal. Data on stockperson behaviour were collected and collated on the basis of the number of positive and negative behaviours used by the stockperson per pig handled so that absolute numbers of both positive and negative behaviours used per pig handled and the percentage of negative behaviours (ie. the ratio of negative behaviours to the total number of behaviours (sum of positive and negative behaviours)) used by each stockperson could be studied.

In both studies (Coleman *et al.*, 1998; Hemsworth *et al.*, 1989), the attitudes of stockpeople towards interacting with their pigs were predictive of the behaviour of the stockpeople towards their pigs, which in turn, was found to be predictive of fear of humans by pigs. For example, the beliefs that considerable verbal and physical effort is required to move pigs and that pigs do not require petting and stroking were correlated with a high percentage of negative behaviours used in handling pigs. Additionally, a high percentage of negative behaviours used by stockpeople was correlated with high fear levels in pigs. Surprisingly, high levels of fear of humans were best predicted when the classification of negative behaviours included not only forceful kicks, hits, slaps and pushes, but also negative behaviours used with less force such as moderate slaps and pushes. This finding further indicates the sensitivity of pigs to moderate negative interactions by humans, something that is not intuitively obvious to most of us.

The development of fear responses in commercial pigs is not surprising considering that stockperson interactions may be biased towards negative ones given that opportunities for positive human contact are probably reduced in modern pig units, due to labour savings that have occurred through facility design and automation, and that many routine husbandry tasks undertaken by stockpeople may contain aversive elements. This bias towards negative interactions together with the sensitivity of pigs to even moderate negative interactions highlights the challenge confronting stockpeople in improving their interactions with pigs and this aspect will be considered later in more detail.

The generality of these relationships between stockperson attitude and behaviour and animal fear, welfare and productivity is demonstrated by similar findings in the dairy industry (Breuer *et al.*, 2000; Hemsworth *et al.*, 2000; Waiblinger *et al.*, 2002) and, to a lesser extent, the poultry industries (Barnett *et al.*, 1992; Hemsworth *et al.*, 1994b, 1996b; Cransberg *et al.*, 2000).

4. Other important job-related characteristics of the stockperson

There is a number of other important human characteristics that are likely to affect animal welfare and productivity in the pig industry such as technical skills and knowledge, job motivation and commitment and job satisfaction of the stockperson (Hemsworth and Coleman, 1998). While the impact of these other characteristics may be more obvious, they have been less researched in the livestock industries than the impact of the stockperson's attitudes and behaviour.

The single most important factor in job performance is the technical skills and knowledge that the person brings to the job (Hemsworth and Coleman, 1998). Knowing and being skilled at the techniques that must be used to accomplish the task are clearly prerequisites to being able to perform that task. There are little empirical data on this topic in the agricultural industries, however this basic premise is universally accepted. These job-related characteristics are therefore likely to be the most limiting factors to job performance in the pig industry in situations where specific technical skills and knowledge are required to perform the tasks. While research and development in livestock agriculture have focused on technological innovation, especially in areas such as housing, nutrition, breeding and health, most of the industry training has generally targeted training supervisors and managers in these new technologies. In comparison, training of stockpeople has often been neglected, perhaps reflecting to some extent the attitude of senior industry personnel to stockperson training (English *et al.*, 1992; Hemsworth and Coleman, 1998).

Work motivation in the livestock industries generally refers to the extent to which a person applies his or her skills and knowledge to the management of the animals under his or her care (Hemsworth and Coleman, 1998). In other words, work motivation is the degree to which the stockperson is reliable, thorough and conscientious in managing his or her animals. High job performance in any industry relies on a combination of motivation, technical knowledge and skills and an opportunity to perform the job and clearly low motivation will limit job performance regardless of technical skills and knowledge of the individual. That is, the stockperson must be motivated in order to achieve high standards of animal welfare and productivity in his or her animals.

Job satisfaction refers to the extent to which a person reacts favourably or unfavourably to his or her work and is thought to derive from the extent to which a person's needs or expectations are being met by the job (Hemsworth and Coleman, 1998). Job satisfaction of the stockperson is likely to affect animal welfare and productivity because of its direct effects on other job-related characteristics such as job motivation and commitment, motivation to learn new skills and knowledge and thus, in turn, technical skills and knowledge. Hemsworth and Coleman (1998) and Coleman (2004) have reviewed some of the personal and job factors that affect both work motivation and job satisfaction, but there are little empirical data to either demonstrate their impact on work performance or the effectiveness of strategies to improve these job-related characteristics in stockpeople.

Human-animal interactions may also influence a number of these job-related variables and thus affect the work performance of the stockperson. For instance, a poor attitude to interacting with animals by affecting ease of handling, may influence the stockperson to the extent that job-related characteristics, such as job satisfaction and work motivation and commitment, may be adversely affected with implication for the job performance of the stockperson. Coleman *et al.* (1998) found that attitudes towards pigs and towards most aspects of working with pigs were correlated with a number of measures of work motivation. Attitudes showed similar relationships with job enjoyment and opinions about working conditions. Thus, the stockperson's attitudes may be related to aspects of work apart from handling of animals and that these influences may impact on animal welfare. A schematic representation of these proposed interrelationships is given in Figure 2.

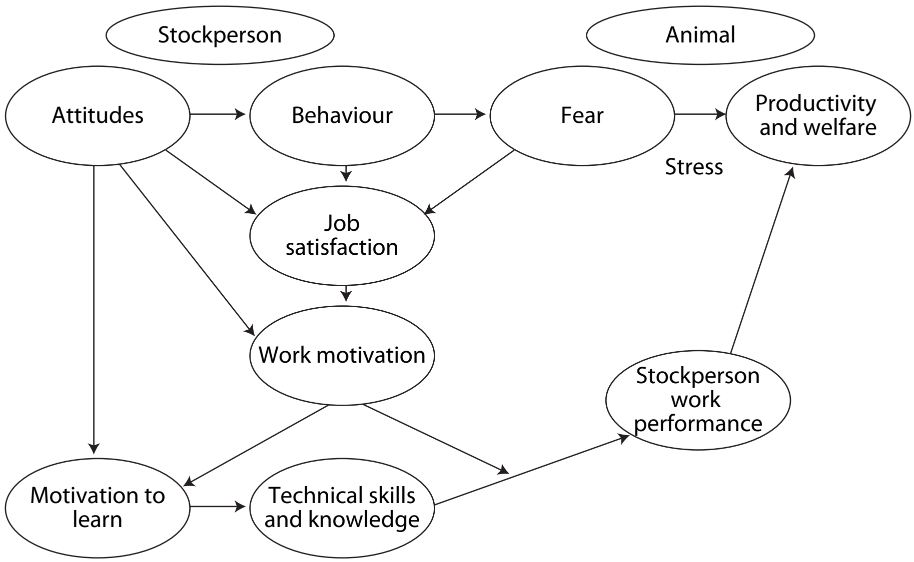

Figure 2. A schematic representation of the proposed interrelationships between a number of key job-related characteristics of the stockperson.

Although there is some disagreement amongst psychologists, a personality trait is generally considered to be a relatively enduring characteristic which exerts a general effect on that person's behaviour and which cannot be observed directly, but can be inferred from the person's behaviour (Coleman, 2004). Most researchers agree that personality can be characterised in terms of the 'big five' personality traits: 'extraversion/introversion'; 'emotional stability'; 'agreeableness'; 'conscientiousness'; and 'intellect' (Barrick and Mount, 1991). It is also generally well accepted that personality factors may be useful in matching people to some kinds of jobs (Barrick and Mount, 1991). For example, discipline and conformity may be important factors in some jobs in which routine tasks are performed by teams of people, while independence, introversion and self-motivation may be important in others in which the tasks are more problematic and where the individual may at times work alone. Indeed there is some limited evidence to support the importance of personality factors in the livestock industries.

Research by Ravel *et al.* (1996) suggests that the importance of personality factors on piglet survival may vary according to the working place, with the relative importance of the traits depending on the type of farm. Self-discipline was a trait that appeared to be important at all farms studied, however high insecurity and low sensitivity were favourable traits in relation to piglet survival at small independent owner-operated farms, while stockpeople that were highly reserved and bold, suspicious, tense and changeable were associated with higher piglet mortality at large integrated farms. Seabrook (1991) reported that pig performance, measured by litter size, was associated with carers with confident personalities, emotional stability, independent personality, rational behaviour and low aggression and, in a study of single-operator dairy herds, Seabrook (1972) found that the highest-yielding herds were those where the stockpeople were introverted and confident. In contrast to these studies, Waiblinger *et al.* (2002) found that personality factors, based on the measures used by Seabrook (1972), were not significantly correlated with cow productivity. However, Waiblinger *et al.* (2002) found that some personality factors were significantly correlated with the attitudes of stockpeople. Agreeableness, which is one of the 'big five' personality traits and is generally considered to be associated with cooperation, good nature and tolerance in a person (Barrick and Mount, 1991), correlated negatively with positive attitude towards awareness of cows and positively with positive attitude towards contact with cows while caring for them. Agreeableness also correlated positively with use of positive behaviours and tended to correlate negatively with the percentage of negative behaviours. However, Coleman *et al.* (2000a) and Coleman (2001) in a study of stockpeople entering the pig industry found no consistent relationships between personality factors, based on the 'big five' measures of personality, and stockperson performance.

English *et al.* (1992) and Hemsworth and Coleman (1998) have suggested that the degree of empathy may predispose people to be good stockpeople. Empathy can be described as the capacity to put oneself in the place of another (Hemsworth and Coleman, 1998) and Coleman (2004) has proposed that stockpeople are likely to perform better if they have a good insight into the emotional responses of the animals under their care. Beveridge (1996) found that empathy towards animals was positively associated with positive attitudes towards interacting with cows and positive beliefs about cows, but was not directly associated with stockperson behaviour towards cows. Coleman *et al.* (1998) found that empathy towards animals was associated with positive beliefs about pigs and about handling pigs and Coleman *et al.* (2000a) and Coleman (2001) found that empathy was associated with positive behaviour towards pigs as well as a high level of intention to remain working in the pig industry. These findings suggest that empathy may be a factor underlying the development of positive attitudes towards pigs.

Hemsworth and Coleman (1998) and, more recently, Coleman (2004) have argued that, while there is little evidence in the livestock industries relating personality and empathy directly to work performance of the stockperson, these characteristics may indirectly affect animal welfare and productivity by influencing the development of the attitudes of the stockpeople to their animals. As discussed in detail by Hemsworth and Coleman (1998), the antecedents of attitudes are many and varied. Demographic variables, various general attitudes and personality traits may indirectly affect behaviour through their influence on attitudes and, while the important dispositional factor in predicting the behaviour of the stockperson is attitude, other dispositional factors, including personality and empathy, may operate indirectly through attitudes. Furthermore, as mentioned earlier, personality factors may be useful in matching people to some kinds of jobs in the livestock industries. For instance, independence, introversion and self-motivation may be important factors in which the tasks are more problematic and where the individual may at times work alone.

Coleman (2004) has recently argued that there is a clear need to identify the attributes which best allow a person to meet the job requirements of a stockperson. These characteristics will be a combination of learned factors, such as handling and observational skills and technical knowledge, and dispositions, such as personality and empathy. The fact that a stockperson is employed in a livestock industry may be a result of a multitude of factors partly geographical and financial, and partly related to the characteristics of the person (Coleman, 2004). Clearly more detailed research is required to identify the full range of personal characteristics that affect the work performance of the stockperson. Such knowledge will be valuable in identifying appropriate training and, perhaps, selection strategies for stockpeople.

5. Opportunities to improve human-animal interactions in the pig industry

The sequential relationships between stockperson attitude and behaviour and pig fear, welfare and productivity demonstrate the opportunities to improve pig welfare and productivity by appropriate selection and training of stockpeople. As discussed earlier, the relationships between other work-related characteristics and animal welfare and productivity, either directly, or indirectly through the attitudes of the stockperson to his or her animals, also indicate that these work-related characteristics should be targeted in the selection and training of stockpeople. Several recent studies in the pig industry demonstrate the potential that exists to improve animal welfare and productivity through training and selection of stockpeople and these results will be briefly discussed.

6. Training

Studies in the pig industry have shown that it is possible to improve the attitudinal and behavioural profiles of stockpeople and, in turn, reduce the level of fear and improve the productivity of commercial pigs (Hemsworth *et al.*, 1994a; Coleman *et al.*, 2000b). This approach in improving the attitudes and behaviour of stockpeople has been described in detail by Hemsworth and Coleman (1998). Basically, cognitive-behavioural training techniques involve retraining people in terms of their behaviour by firstly targeting both the beliefs that underlie the behaviour (attitude) and the behaviour in question and secondly, maintaining these changed beliefs and behaviour. This process of inducing behavioural change is really a comprehensive procedure in which all of the personal and external factors that are relevant to the behavioural situation are explicitly targeted.

Hemsworth *et al.* (1994a) found that targeting the key stockperson attitudes and behaviour that are correlated with level of fear of humans in pigs resulted in stockpeople having a more positive attitude towards their pigs, with subsequent reductions in the proportion of negative interactions towards their animals and reductions in the animals' fear of humans (Table 3). Furthermore, there was a marked tendency for an improvement in the reproductive performance of the pigs at the farms in which this training programme was introduced. Cognitive-behavioural training of stockpeople has also been shown to be effective in decreasing animal fear and improving animal productivity in the dairy industry (Hemsworth *et al.*, 2002).

As Hemsworth and Coleman (1998) have discussed, the stockperson also requires a basic knowledge of both the behaviour and requirements of farm animals together with a range of well developed husbandry and management skills to effectively care for and manage farm animals. These are skilled tasks and stockpeople are therefore

Table 3. Summary of the effects of a cognitive-behavioural intervention procedure, applied at Modification farms, targeting the attitudes and behaviour of stockpeople in the pig industry (Hemsworth et al. *(1994a).*

Variables	Control farms	Modification farms
Human attitudes[1]		
Beliefs about petting and talking	89.2	102.9
Beliefs about effort needed to handle	89.8	92.2
Human behaviour		
Negative tactile behaviours (%)	55.8	38.6
Fear levels		
Time spent near experimenter (s)	15.6	21.9
Number of interactions with experimenter	1.3	2.0
Reproductive performance		
Piglets born/sow/year	22.2	23.8

[1]High score indicates positive beliefs.

required to be competent in many of these tasks. Clearly the conventional training of stockpeople to develop such competencies should be a systematically and soundly implemented process in which the requirements of both the stockperson and the industry are addressed.

7. Selection of stockpeople

It is clear that pig welfare and productivity can be improved by both cognitive-behavioural training which targets attitudes and behaviour of stockpeople as well as conventional training which targets the technical skills and knowledge of stockpeople necessary to effectively care and manage pigs. It is also important to identify those characteristics which identify potentially good stockpeople.

The potential value of selecting stockpeople using screening aids is well illustrated by a recent study in the Australian pig industry. One hundred and forty-four inexperienced stockpeople completed a series of computerised job-related questionnaires (Coleman *et al.*, 2000a; Coleman, 2001). After six months of employment, the behaviour towards pigs, technical knowledge and work motivation and commitment of the stockpeople were directly assessed by an independent observer and a supervisor's report of satisfaction and conscientiousness was used to measure these other aspects of stockperson performance.

A positive attitude towards the characteristics of pigs was a significant predictor of positive behaviour towards pigs and technical skills and knowledge, but not of work motivation and commitment. This suggests that attitude towards pigs is a good predictor of performance relating specifically to working with pigs, but not to general work motivation and commitment. Empathy towards animals correlated with technical knowledge and behaviour towards pigs however, there were no consistent correlations between personality factors, based on the 'big five' measures of personality, and stockperson performance. Another significant finding was that a pre-employment measure of potential performance called the PDI-Performance measure was found to be a good predictor of all measures of actual observed performance of the stockpeople. A person scoring high on this measure is likely to adhere to rules, show stability of behaviour, take care while performing tasks and take responsibility. The results from this study suggest that this measure may be a useful tool to help select stockpeople who will perform well in the ways studied here.

These recent results (Coleman *et al.*, 2000a; Coleman, 2001) indicate that job-related characteristics such as empathy, attitudes towards animals and towards aspects of work may be useful in identifying inexperienced people who are likely to be good stockpeople and thus, potentially such tests could be assembled into a kit for use in selection in the pig industry. However, there are several cautionary points that should be made. For example, as with all selection tools, care should be taken to use such findings as a guide in selection and not a prescription. It is essential that a validation study be carried out before the findings of this study are implemented widely. Because there is an increasing recognition of the need to employ people who will be adaptable, conscientious and who will treat animals well, it is likely that a demand will develop for a selection procedure which can be widely used in the industry.

In addition to assisting in selecting stockpeople, assessing the key job-related characteristics of stockpeople may also provide the pig industry with a good opportunity to monitor the potential impact of individual stockpeople on animal welfare. Screening aids such as attitude and job motivation questionnaires may identify both weaknesses in individual stockpeople and targeted training for these individuals.

8. Conclusion

Research in the pig industry has clearly shown that the behaviour of stockpeople can result in commercial pigs developing fear responses to humans, which can have large adverse effects on pig welfare and productivity. Even moderate negative interactions such as slaps if frequently used will result in pigs becoming fearful of humans. It is these fear levels, through stress, that may adversely affect pig welfare and productivity. Furthermore, these human-animal interactions may influence the stockperson to the extent that job-related characteristics, such as job satisfaction and work motivation, may be affected with implication for the work performance of the stockperson.

The sequential relationships between human and animal variables indicate that there is an opportunity to target stockperson attitudes and behaviour in order to improve pig welfare. Stockperson selection and training programs addressing these key attitudinal and behavioural profiles appear to offer the pig industry excellent potential to improve pig welfare.

Studies in the pig industry have shown the potential of cognitive-behavioural training designed to specifically target these key attitudes and behaviours of stockpeople. These studies have also demonstrated that such training is practical and is effective on a wide range of stockpeople working in a variety of situations. Therefore, there is a strong case for introducing this training in the pig industry and a commercial multimedia training program called 'ProHand' (Animal Welfare Science Centre, 2005), which targets the attitudes and behaviour of the stockperson, is available and is currently used in Australia, New Zealand and the USA.

The modern stockperson also requires a basic knowledge of both the behaviour of the farm animals and their requirements together with a range of well developed husbandry and management skills to effectively care for and manage farm animals. Therefore, conventional training of stockpeople to develop such competencies should be considered as fundamental in improving the welfare of commercial pigs.

Understanding and assessing other key job-related characteristics of stockpeople may also provide the pig industry with a good opportunity to monitor the potential impact of individual stockpeople on animal welfare. Screening aids such as attitude and job motivation questionnaires may be valuable in both assisting in selecting desirable stockpeople and also in identifying training needs in individual stockpeople.

In conclusion, there is a clear need to reduce the limitations that human-animal interactions impose on the welfare of commercial pigs. While our understanding of the regulation and impact of human-animal interactions has improved considerably over the last decade or so, recognition of the role of stockpeople on the welfare and productivity of livestock has only recently occurred. Much has been done to improve genetics, nutrition, health and housing of pigs but efforts to target the stockperson, who performs such a key function, has just begun. It is likely in the near future that both the livestock industries and the general community will place an increasing emphasis on ensuring the competency of stockpeople to manage the welfare of farm animals. Appropriate strategies to recruit and train stockpeople in the pig industry will be integral in safeguarding the welfare of commercial pigs.

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Chapter 11. The welfare of pigs: a social, ethical and scientific issue[1]

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Abstract

As pig production shifted from small-scale to large-scale methods, concern over animal welfare changed from concern over known individual animals to a more abstract issue that has attracted significant public attention. In the resulting debate, different viewpoints on animal welfare emerged. These generally emphasise (1) the affective states of animals, especially negative states such as pain and fear, (2) the basic health and functioning of animals, and (3) the ability of animals to live according to their natures and carry out their natural behaviour. One outcome of public concern over animal welfare was the development of animal welfare science as a multi-disciplinary field in which the study of animal behaviour plays a particularly strong role. Behavioural research has (for example) helped people understand and prevent harmful behaviour, improve housing and handling methods, and identify elements of natural behaviour that are important for animal welfare. Other research has used traditional veterinary, agricultural and physiological measures to diagnose and prevent animal health problems, and to compare the effects of different housing and handling practices. Public concern over animal welfare has also resulted in various animal welfare assurance programs in the form of voluntary codes, regulations, international agreements, corporate policies, and product differentiation schemes. These programs include various requirements, some designed to promote good health and functioning, others to mitigate unpleasant affective states, and others to allow more natural living conditions or natural behaviour. Animal welfare science has great potential to improve conditions for animals, often while providing benefits to animal producers as well. The research and its benefits need to be communicated effectively in order for animal welfare science to be translated into practical improvements in the lives of animals.

Keywords: pigs, animal welfare, health, behaviour, animal welfare standards

[1] Portions of this text are taken from the book *Understanding Animal Welfare: Science in its Cultural Context*, to be published by Blackwell Publishing. I am grateful to Blackwell Publishing for permission to use the material here.

1. Introduction

In Victorian England it was common for families to raise a pig. The pig was typically purchased as a weanling in the spring, kept in a lean-to sty adjacent to the cottage where the family lived, and fed on food waste and vegetation gathered by its human caretakers. The pig would then be killed, typically early in the winter when the first cold weather allowed the carcass to be chilled (Malcolmson and Mastoris, 1998).

The 'cottage pig' thus became a kind of edible pet: it provided food, but it also was a source of pride and companionship. In her classic autobiographical fiction about English country life, Flora Thompson noted the role that the pig played:

> 'During its life the pig was an important member of the family, and its health and condition were regularly reported in letters to children away from home, together with news of their brothers and sisters. Men callers on Sunday afternoons came, not to see the family, but the pig, and would lounge with its owner against the pigsty door for an hour, scratching piggy's back and praising his points or turning up their own noses in criticism' (Thompson, 1939-1943).

With these close and personal relations between the family and the pig, the killing of the animal was a notable day in the annual calendar. The pig was normally killed at night when the day's labour was over, amidst a scene (as Thompson described it) of 'mud and blood, flaring lights and dark shadows'. Children 'would steal out of bed to the window' to watch, but the more sensitive members of the family found it troubling. Thompson described the reaction of her fictional heroine who 'felt sick and would creep back into bed and cry: she was sorry for the pig'.

In the 1900s, as pig rearing moved gradually from small-scale cottage production to large-scale commercial production, concern over the welfare of pigs did not disappear but it changed in important ways. Instead of sympathy for individual animals based on a close interpersonal connection, animal welfare became a more abstract concern. For some conscientious animal producers who raise thousands of pigs each year, animal welfare became a matter of professional pride in raising animals well and successfully. For the critics of large-scale confinement production methods, animal welfare became an issue of social conscience. People, even those with no personal involvement with pigs, came to question the appropriateness of modern pig-keeping methods, and they were troubled over the quality of life of animals on modern farms.

The result has been a vigorous debate over the welfare of farm animals, which in turn led to changes in practices for raising and handling animals, to scientific research on animal welfare, and to standards, regulations, and other programs intended to ensure a high level of animal welfare. This chapter provides a brief overview of these topics, with emphasis on the development of animal welfare science and its application in practice and in welfare assurance programs.

2. Debate about animal welfare

Contemporary debate about the welfare of animals in confinement production systems began in earnest in 1964 with the publication of a book entitled *Animal Machines* (Harrison, 1964). The book was serialised in a major British newspaper, and it caused enormous public concern, initially in the United Kingdom and subsequently in other countries, about the then-new confinement systems. In the book, author Ruth Harrison claimed that the new systems were causing widespread animal suffering simply because they had been designed to achieve the typical industrial goals of productivity, efficiency and profit. To a human population that had tended to equate animal suffering with acts of deliberate cruelty, it came as a shock to be told that animal suffering on a vast scale was occurring throughout the countryside simply through the pursuit of normal business objectives.

One outcome of the concern was a sustained debate about what constitutes animal welfare and what evidence could be used to determine whether an animal's state of welfare is good or bad. One view, which was especially common among animal protection advocates, put particular emphasis on the 'affective states' of animals – that is, states that are experienced by the animal as hedonically positive or negative, especially pain, distress and suffering. For example, humane advocate Richard Ryder argued that it is the ability to experience 'pain' (in which he included 'all states of suffering') that makes animals objects of moral concern (Ryder, 1998). Other commentators took a broader view that included positive affect as well. For example, Ruth Harrison asked, 'Have we the right to rob [farm animals] of all pleasure in life simply to make more money more quickly out of their carcasses?' (Harrison, 1964).

A contrasting view, which came especially from animal producers and certain veterinarians and animal scientists, linked animal welfare to the physical health and productivity of animals. For example, veterinarian David Sainsbury emphasised health as a critical factor in animal welfare:

> 'Good health is the birthright of every animal that we rear, whether intensively or otherwise. If it becomes diseased we have failed in our duty to the animal and subjected it to a degree of suffering that cannot be readily estimated' (Sainsbury, 1986).

A committee formed by the British government to recommend further action on animal welfare reported hearing a more narrow interpretation:

> 'Many witnesses have represented to us that the growth rate of an animal for meat or the egg production of a laying hen are the only reliable objective measures of their welfare. It is claimed that suffering of any kind is reflected by a corresponding fall in productivity. The argument is that in the absence of any scientific method of evaluating whether an animal is suffering, its continued productivity should be taken as decisive evidence that it is not' (Brambell, 1965).

A third view held that for animals to have satisfactory welfare, they must be able to live in a manner that corresponds to their 'nature' and that does not prevent them from carrying out their natural behaviour. Thus philosopher Bernard Rollin (1993) proposed that animal welfare is not just about 'control of pain and suffering', it also entails the 'nurturing and fulfilment of the animals' natures'. The view is linked in part to the controversial idea that animals have 'behavioural needs' to act in certain ways (see Jensen and Toates, 1993; Duncan, 1998). Writing about organic animal production, scientist Susanne Waiblinger and colleagues stated, 'It is not important to "prove" that a sow needs to root or a hen needs to dust bathe, because these are natural behaviours belonging to the animal's species-specific nature'. And they argued that organic husbandry should 'develop more innovative systems in which all aspects of natural behaviour are taken into account' (Waiblinger *et al.*, 2004). Such views are often shared by urban consumers. A Dutch study of people's views on animal welfare found that whereas livestock producers tended to equate animal welfare with physical health, consumers tended to emphasise 'freedom to move and freedom to fulfill natural desires' (Te Velde *et al.*, 2002).

These different viewpoints have created a complex and sometimes contradictory discourse about 'animal welfare'. Thus, for example, an organic pig producer might claim that animal welfare is better on pasture than in confinement because the animals live more freely, even if parasites and neonatal deaths are not as well controlled, whereas a confinement producer might claim the opposite.

The different views of animal welfare have also created a complex agenda for the scientific study of animal welfare. Some scientists have pursued animal welfare by seeking ways to eliminate problems of basic health and functioning of animals such as neonatal deaths, infectious diseases, growth-check after weaning, behavioural abnormalities, and physiological stress responses. Others have focused on affective states by trying to quantify and mitigate pain, fear, hunger and separation distress. Others have tried to identify those elements of natural behaviour that are important for animals to perform, and to accommodate such elements in feasible ways. The result is a complex set of activities all assumed under the general heading of animal welfare science.

3. Animal welfare science

The scientific study of animal welfare was shaped initially by historical events whose influence can still be seen today. In the wake of the controversy created by *Animal Machines*, the British government appointed a committee to investigate 'the welfare of animals kept under intensive livestock husbandry systems'. The committee included a number of distinguished scientists who saw an important role for scientific research to play in addressing the issues (Brambell, 1965).

One of the scientists was animal behaviourist William Thorpe who, as an appendix to the committee report, wrote a thoughtful essay on how one might use the tools of science to better understand animal welfare (Thorpe, 1965). He mentioned physiological indicators of stress, behavioural indicators of pain and discomfort, studies of motivation that is thwarted in confinement, studies of the intelligence and cognitive powers of animals, studies of animals' capacity to develop a learned fear of humans, and studies of the preferences that animals show for different environments. It was a vision that involved several fields of science, yet Thorpe's home field of animal behaviour was especially prominent. The committee, accordingly, called for research to be done in veterinary medicine, stress physiology, animal science, and particularly in animal behaviour, partly to improve animal production systems in practical ways, and partly to identify how the welfare of animals is influenced by different production methods (Brambell, 1965). Based on this advice, the early funding for animal welfare research in Britain created a multi-disciplinary approach with animal behaviour playing a particularly strong role. A few examples will serve to illustrate the types of the research that developed.

In some cases, welfare problems lent themselves to research and improvement through the traditional application of pathology, epidemiology, and other branches of veterinary science. As a veterinary pathologist, Ernest Sanford was confronted with a surprising number of sows arriving for *post-mortem* examination in seemingly good condition but showing a fatal torsion of the stomach and spleen. In looking into the cases he found that many were from confinement units that practiced alternate-day feeding. For sows that are kept on pasture, producers will sometimes limit the animals' food intake by delivering an abundant amount of food every second day so that the animals can eat their fill without having to compete for a limited food supply, and on alternate days they forage on hay or other roughage. However, alternate-day feeding was also adopted by some confinement producers for sows in gestation stalls. Under these conditions the animals became intensely excited at feeding time, and those that were last to be fed often worked themselves into a frenzy while waiting for their food to arrive, and then they bolted down a quantity of food that would last them for the next two days. Sanford also noted that gastro-splenic torsion was most common on weekends – times when there was likely to be reduced staff and perhaps only one person feeding hundreds of sows who thus had to wait longer than usual to be fed. Putting these observations together Sanford concluded that the problem was due to a combination of excessive hunger, over-excitement and rapid eating (Sanford *et al.*, 1984). Improvements could be made by doing away with alternate-day feeding for sows in confinement, and by using automatic feeding systems whereby food is dropped simultaneously to all sows at the throw of a switch so that the animals would remain relatively calm at feeding time.

Other research used measures drawn from animal production science. In a classic study of 12 small pig farms in the Netherlands, Paul Hemsworth and co-workers observed that although the farms used the same feed, the same breeding stock and similar buildings, different farms had very different levels of reproductive performance. Observing the animals, Hemsworth found that on farms with high levels of productivity, the sows showed little fear when approached by an unfamiliar human visitor, whereas on farms with lower productivity the animals tended to shy away (Hemsworth *et al.*, 1981). This led to an extensive body of research showing that negative handling of animals by human caretakers leads, in many species, to a chronic fear of humans which is often correlated with reduced growth and reduced reproductive success (Hemsworth and Coleman, 1998).

Physiologist John Barnett and colleagues have made extensive use of physiological 'stress responses' in their assessment of housing methods for sows. In a series of studies Barnett and co-workers housed sows in individual stalls, tethers and various forms of loose housing, and they monitored levels of free (i.e. unbound) corticosteroids in samples of blood. One study showed a significant, chronic increase in free corticosteroid levels in animals kept in tethers compared to all other systems. Based on this and other evidence, the team concluded that the tether system was causing 'a chronic stress response and a significant metabolic cost' (Barnett *et al.*, 1985). Later observations clarified the cause of the problem. In the tether system used for this research, the short partitions that separated the heads of adjacent sows were relatively open and allowed substantial aggression between neighbouring animals. In a follow-up study, the partitions were covered. Under these conditions there was virtually no aggression, and the level of plasma corticosteroids was no higher than in other housing systems. The authors concluded that the lower welfare seen in the tethers resulted from design features that allowed continual aggression to occur (Barnett *et al.*, 1987).

Research on animal behaviour has played a variety of roles in understanding and improving animal welfare. In some cases, behavioural observations have led to a better understanding of the causes of harmful behaviour. Traumatic injury of piglets that are crushed or trampled by their mothers is both a serious animal welfare problem and an important cause of commercial loss. Peter English and William Smith (1975) monitored the early behaviour of nearly one thousand piglets, 236 of which subsequently died before weaning. Although many of the deaths were caused by crushing, nearly half of the victims showed signs of malnutrition before the fatal event. Presumably, malnourished piglets are less able to escape sudden movements of the sow, and they may remain at the udder between nursing episodes where they are more at risk of being crushed. The work led to the realisation that preventing crushing requires not only control of the movements of the sow, but also interventions such as cross-fostering and supplementary feeding to prevent the malnutrition that creates a heightened risk.

In other cases, behavioural research has helped to improve the design of animal handling equipment. Ramps are widely used for loading pigs, and occasionally in special kinds of housing that involve more than one level, but pigs balk at walking up certain ramps for reasons that were poorly understood. Peter Phillips and co-workers (1988) monitored the preferences shown by pigs for different ramps as a way of identifying the design features that are most important to the animals. He set up a room with a small holding pen surrounded by four ramps that pigs were free to walk up and down as they wished. Phillips did a series of experiments, each one comparing a different design feature: one experiment used ramps with four different slopes; another compared four levels of illumination; and so on. He found that pigs showed striking preferences among ramps at different angles, generally avoiding ramps steeper than 25 degrees. Another important factor was the spacing of horizontal cleats attached to the ramp to provide secure footing: pigs preferred ramps with cleats spaced every 5 to 10 cm, but largely avoided ramps with cleats farther apart. When other factors were varied (level of illumination, ramp width, enclosure of the side walls), the pigs showed no particular preferences for one ramp ahead of another. In this way Phillips used preference research to identify the design features that make ramps more or less acceptable to the animals.

Research has been done to identify how strongly animals in captivity are motivated to perform elements of their natural behaviour. When a sow kept outdoors is about to farrow, she goes through an elaborate procedure of exploring the environment, finding a suitable nesting site, rooting out a depression, and then carrying straw and other material and fashioning it into a large nest (Jensen, 1986). All this behaviour is prevented in typical farrowing crates. However, engineer Mike Baxter (1983) had proposed that the sow's motivation to build a nest could be eliminated by providing a suitable pre-formed nest. This idea was tested by Dale Arey and coworkers. They observed sows making nests before farrowing, and they quantified the time the animals spent in the major nest-building activities. They also recorded the physical features of the nests the sows built. Arey then provided other sows with pre-formed nests, similar to what the sows themselves had built, and observed how the sows responded. Instead of just accepting the pre-formed nests and settling down to farrow, the sows still went through elaborate nest-building. Arey and co-workers concluded that the sow's motivation to build a nest, is not eliminated by providing a suitable pre-formed nest, and that 'farrowing accommodation should therefore enable sows to perform nest building' (Arey *et al.*, 1991).

The above examples illustrate some of the diversity within animal welfare research, but this very diversity has created problems of interpretation. Practices such as Segregated Early Weaning are arguably very unnatural for the animals and may result in sustained separation distress, but they can be effective in preventing infectious diseases (Robert *et al.*, 1999). Keeping animals in free range or loose housing systems is seemingly more natural, but it may lead to problems of illness and neonatal deaths (Edwards, 1995; Cox and Bilkei, 2004). Hence there is scope for different types of research (all done in the name of animal welfare) to lead to different conclusions. For example, different scientists have reached different conclusions about the welfare implications of gestation stalls, partly because they adopted different views of animal welfare and emphasised different scientific measures (Fraser, 2003). One of the challenges in interpreting animal welfare research is to avoid mistaking disagreements about technical, factual matters with disagreements that arise when scientists base their research on different views of animal welfare.

4. Animal welfare assurance programs

Another important response to public concern over farm animal welfare was the evolution of programs designed to ensure (and assure the public) that satisfactory safeguards are in place to protect animal welfare (Fraser, 2006).

In several countries and industries, the first step was some form of voluntary guidelines or 'codes of practice' for the welfare of animals. In the aftermath of *Animal Machines*, the British government commissioned the writing of codes of practice to outline how farm animals ought to be kept. The codes were voluntary, but an Act of Parliament passed in 1968 stipulated that failure to follow the codes could be used as evidence if a person was charged with causing animals unnecessary pain or distress; and in 1988 new regulations turned some of the provisions of the codes (e.g., space requirements for hens in cages) into legal requirements (Radford, 2001). Similar codes, some purely voluntary and others with varying degrees of legal or other recognition, were subsequently created in a number of countries by governments, industry organisations, and other bodies.

The situation unfolded quite differently in Sweden. There, the public campaign for reform was led by Astrid Lindgren, the famous author of such children's classics as *Pippi Longstocking* and *Emil and his Clever Pig*, books that depicted children and animals living happy, independent lives. Lindgren began in the 1980s to write letters to the major Swedish newspaper castigating the national government for allowing farmers to keep animals under restrictive, unnatural conditions (Anonymous, 1989). The government responded by passing a new Animal Protection Ordinance (1988) that followed Lindgren's criticisms to a remarkable degree. Rather than simply regulating certain variables such as space allowance, the Animal Protection Ordinance required that hens not be kept in cages, that dairy cattle have access to pasture in the summer, and that barns be fitted with windows that let in natural daylight.

However, national legislation could do only so much. When the United Kingdom banned the narrow veal calf crate, there was an existing export of calves from British farms to France and the Netherlands where crates were still in widespread use, and nothing in the new legislation could prevent the export from continuing. Moreover, trade agreements made it impossible for the United Kingdom to block the import of veal from France and the Netherlands, possibly from the very animals that had previously been shipped from the United Kingdom. The situation became particularly intolerable when the farmer-turned-politician who served as minister of agriculture could not provide assurances that his own calves were not involved in this trade (RSPCA, 1995).

The upshot was a concerted effort to bring trading partners into line with a common set of standards. In the 1980s and 1990s the European Union began passing directives – agreements that member countries are obliged to translate into national law – governing production methods for hens, veal calves and pigs. The early directives generally specified quantitative standards such as minimum space allowances. Roughly ten years later, however, a new set of directives took a much more reformist stance by requiring countries to phase out or limit the use of narrow crates for veal calves by 2007, standard cages for hens by 2012, and individual gestation stalls for sows by 2013 (Stevenson, 2004). An even more international approach to standards began in 2001 when the 167 member countries of the World Organisation for Animal Health voted to begin developing global animal welfare standards, and the first output – a set of guidelines for slaughter, transport, and killing of animals in disease eradication – was approved in 2005 (OIE, 2005).

Nonetheless, in many countries the national government lacked either the political will or the constitutional power to create national laws regarding animal welfare, and other sectors of society took up the lead. Around the year 2000, McDonald's Restaurants in the United States announced that the company would require certain animal welfare standards to be met by their suppliers, especially in the slaughter and egg industries. Burger King and other companies followed suit and soon began expanding their programs to other countries. In some respects, such corporate programs serve as an alternative (or complement) to industry guidelines and regulatory approaches (Brown and Hollingsworth, 2005).

Even where some form of national standard was in place, certain producers, retail companies and animal welfare charities decided to take the further step of creating product differentiation programs that would allow conscientious consumers to purchase products produced according to specific standards. Perhaps the best established of these is Freedom Food, begun in 1994 by the Royal Society for the Prevention of Cruelty to Animals in the United Kingdom. It uses an active program of inspection and labeling to guarantee that the animals have been raised, transported and slaughtered in accordance with specific standards (RSPCA, 2007).

The result of all this activity is a range of programs – voluntary codes, laws, international agreements, corporate programs, and product differentiation schemes – all functioning in different ways but all designed or claimed to protect animal welfare.

To make matters more confusing, different programs include different requirements, at least partly because they reflect different views of animal welfare. Some requirements are designed to prevent or mitigate pain and suffering, for example by limiting the use of electric goads to move animals, or by requiring that some form of anaesthesia be used for certain painful procedures. Others are designed to prevent reductions in health or growth, for example by stipulating stocking densities or ammonia levels beyond which the animals' health or performance would be impaired. Others are designed to allow animals to live in a more natural manner, for example by requiring certain freedom of movement or access to resources such as roughage that would allow natural foraging behaviour. Many or all of these requirements have some basis in animal welfare science. The science has shown, for example, that certain levels of crowding can reduce growth, that certain handling methods create fear, and that animals are motivated to carry out certain elements of their natural behaviour. Hence, many of the programs differ not because some are based on science and the others are not, but because they emphasise different animal welfare objectives to different degrees.

5. The application of animal welfare science

As this book amply illustrates, animal welfare science has great potential to improve the raising, handling, transportation and slaughter of animals in practical ways that benefit both animals and animal producers. However, as with most science there is often a lag between the research and its application. With the small number of animal welfare scientists and the vast numbers of people who keep animals worldwide, communicating the science to its ultimate users is a mammoth challenge. The one promising but long-term strategy is to incorporate animal welfare science into the education of veterinary and agricultural students, who will then be in a position to implement the research and carry the messages to other potential users.

Fortunately, there are often practical incentives to improve animal welfare. As we saw in the research by Paul Hemsworth, positive handling of animals not only improves their welfare by eliminating chronic fear, it can also lead to greater commercial productivity. Managing piglets to avoid malnutrition and crushing contributes not only to the animals' welfare but also helps reduce a major cost to the producer. Reducing stress during transportation and pre-slaughter management is not only better for the animals, it also helps to avoid major problems of meat quality. In these and many other respects, practical benefits can provide a major incentive for improving animal welfare. Especially in cultures where public concern over animal welfare is not highly developed, it will be important to communicate the practical advantages of good animal welfare practices.

But the practical benefits of animal welfare research raise a perplexing question: given that modern changes in animal production are often thought to be based on science, why is it that such fundamental problems as crowding, negative handling and harmful animal behaviour remained under-researched and unresolved for so long? Perhaps part of the answer lies in the transition from 'animal husbandry' to 'animal science'. In the early 1900s, many agricultural and veterinary students studied a subject called 'animal husbandry'. It included the feeding, breeding, health care, handling, management and housing of animals. With the development of the biological sciences, animal husbandry was replaced by 'animal science'. The feeding of animals became the science of nutrition; the breeding of animals became the sciences of genetics and reproductive physiology. But other elements of animal husbandry – handling, management and housing – were largely ignored as topics for scientific research. By applying systematic investigation to these topics, animal welfare research is now helping to fill some of the large gaps that were left when animal husbandry became animal science. And given the advances that have already been made in nutrition, reproductive physiology and other fields, animal welfare science may well provide the next generation of improvements in animal production.

However, the approach will differ from that used in traditional animal science. Traditionally, animal science has tried to improve the productivity, efficiency and profitability of animal production, whether or not the animals themselves benefit from the changes. Thus, for example, animal science research showed that crowding pigs to a degree that is clearly detrimental to the animals may still provide the best return on the producer's investment in buildings and equipment (Kornegay and Notter, 1984), and that the use of finely ground grain can improve the commercial performance of pigs even though it increases the severity of stomach ulcers (Wondra *et al.*, 1995). In these and other cases, traditional animal science has sometimes encouraged practices that are detrimental to the animals themselves. Because animal welfare research focuses first and foremost on benefits for the animals – their health, comfort, emotions and motivations – it should provide practical improvements for the raising and handling of animals, but in ways that make a better fit to public concern over the welfare of animals.

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